# HOMESTAKE MINING COMPANY OF CALIFORNIA

## Grants Reclamation Project

# GROUNDWATER FLOW AND TRANSPORT MODELING WORK PLAN

March 2018

U.S. Nuclear Regulatory Commission License SUA-1471
State of New Mexico DP-200

Grants Project

Homestake Mining Company of California

Thomas Wohlford
*Closure Manager*

24 March 2018

**Document Control Desk**
U.S. Nuclear Regulatory Commission,
Washington, DC 20555–0001

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**Mr. Jeffrey Whited**
Materials Decommissioning Branch (Mail Stop T-8F5)
Decommissioning, Uranium Recovery, & Waste Programs
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555–0001

**Mr. William Pearson**
Ground Water Quality Bureau
New Mexico Environment Department
PO Box 5469
Santa Fe, NM 87502-5469

**ATTN: Mr. Sairam Appaji**
Region VI Superfund Division
1445 Ross Avenue, Suite 1200
6SF-LP
Dallas, TX 75202-2733

**RE: San Mateo Creek Basin and HMC Mill Groundwater Model Plan**

Dear Sirs:

Homestake Mining Company of California (HMC) is working to create an updated groundwater flow model for the Grants Reclamation Project (GRP). The HMC flow model will be used to simulate current GRP groundwater restoration activities and as a tool to predict future remediation efforts including fate and transport of site constituents of concern. The new groundwater model will be a basin-wide model, encompassing the entire San Mateo watershed basin. This is a departure from the older model which was localized to just the immediate environs of the GRP. The attached report is a summary of the proposed groundwater model construction for the San Mateo Creek basin and the HMC GRP. After submittal of this report, the next step is to construct the groundwater model which will be used for the completion of a revised Groundwater Closure Action Plan (CAP) for the GRP.

Thank you for your time and attention on this matter. If you have any questions, please contact me at the Grants office at 505.287.4456, extension 34, or call me directly on my cell phone at 505.290.2187.

NMSS01

Respectfully,

Thomas D. Wohlford

**Thomas Wohlford**
Closure Manager
Homestake Mining Company of California
Office: 505.287.4456 x34 | Cell: 505.290.2187

Copy To:

B. Tsosie, DOE, Grand Junction, Colorado (electronic copy)
M. McCarthy, Barrick, Salt Lake City, Utah (electronic copy)
C. Burton, Barrick, Henderson, Nevada (electronic copy)
R. Wykoff, Brown & Caldwell, Lakewood, Colorado (electronic copy)

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# List of Abbreviations

| | |
|---|---|
| ac-ft | acre-foot/feet |
| ACM | asbestos containing material |
| amsl | above mean sea level |
| BC | Brown and Caldwell |
| COCs | Constituents of Concern |
| d | day(s) |
| EP | evaporation pond |
| ft | foot/feet |
| $ft^2$ | square foot/feet |
| gpm | gallon(s) per minute |
| GRP | Grants Reclamation Project |
| HMC | Homestake Mining Company of California |
| HSCM | hydrogeologic site conceptual model |
| L | liter(s) |
| LTP | large tailings pile |
| mg | milligram(s) |
| NMONRT | New Mexico Office of Natural Resources Trustees |
| Regional HSCM | hydrogeologic site conceptual model for the surrounding San Mateo Creek groundwater basin |
| RI | Remedial Investigation report |
| RO | reverse osmosis |
| SAG | San Andres/Glorieta |
| Site HSCM | hydrogeologic site conceptual model for the Homestake Mining Company Mill Site |

| | |
|---|---|
| SMC | San Mateo Creek |
| SOW | scope of work |
| STP | small tailings pile |
| TDS | total dissolved solids |
| U.S. DOE | United States Department of Energy |
| U.S. EPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |

# Section 1: Introduction

Homestake Mining Company of California (HMC) is creating a Groundwater Flow and Transport Model for HMC's Grants Reclamation Project (GRP) located in the San Mateo Creek (SMC) basin near Grants, New Mexico. The groundwater flow model will be used to simulate current GRP groundwater restoration activities and as a tool to predict future remediation efforts including fate and transport of site constituents of concern (COCs). This model will be a valuable tool for completion of a revised Groundwater Corrective Action Plan (CAP) for the GRP. A bulleted of potential model uses is as follows;

- Simulation of groundwater flow and hydraulic heads within the alluvial and bedrock (upper, middle and lower Chinle and San Andres) aquifers beneath the GRP.
- Simulation of fate and transport of site Constituents of Concern (COCs) for the GRP.
- Prediction of remediation time frame for GRP using current groundwater pump and treat methodology.
- If necessary, analysis of remedial alternatives associated with the GRP
- Simulation of groundwater flow and hydraulic heads for the regional-scale alluvial and bedrock aquifers within the San Mateo Watershed (SMC Basin).
- Simulation of fate and transport of COCs from the Ambrosia Lake area of the SMC Basin.
- Prediction of off-site San Mateo uranium-selenium plume movement towards the GRP.

The new groundwater model will be a basin-wide model, encompassing the entire San Mateo watershed basin. This is a departure from the older groundwater flow model which was localized to just the immediate environs of the GRP. This report includes task descriptions associated with development of both a site-specific and a regional groundwater flow and transport model in support of assessments of ongoing corrective action planning for the HMC Mill Site. The Plan describes major tasks associated with the development of site-scale (SOW Phase 3) and regional (SOW Phase 4) flow and transport models, along with the ultimate merger into a single groundwater flow model (SOW Phase 5). The schedule for the groundwater model completion is included in Appendix A.

## 1.1 Background Information

The HMC Mill site is located about 6 miles north of Grants in the SMC Basin, which encompasses an area of approximately 321 square miles and is shown by the blue outline on Figure 1. The SMC Basin includes the Grants Mineral Belt, which produced more uranium than any other district in the world during the period 1951–1980 (HDR, 2016). There are more than 85 legacy mining and mill sites in the SMC Basin and mining and remediation activities have had a significant impact on local and regional groundwater flow conditions and water quality.

Significant remedial activities have occurred in four uranium mill sites in the SMC Basin, which are shown on Figure 2. These include the HMC Mill site and Bluewater Mill site in the lower (southern) SMC Basin, which is defined as the portion below the confluence of San Mateo and Arroyo del Puerto (Figures 1 and 2). The Rio Algom/Quivira Mill site (also referred to as the Ambrosia Lake Mill site) and the Phillips Mill site in the Ambrosia Lake area are located in the upper (northern) SMC Basin about 12 miles north of the HMC Mill site (Figures 1 and 2). Significant groundwater data have been collected at these sites associated with past and ongoing remedial activities.

HMC Mill site features are shown on Figure 3, and include former uranium milling operation areas, tailing piles, collection and evaporation ponds, a water treatment plant, and support facilities. At the HMC Mill site, uranium milling operations occurred from 1958 until 1990. Closure activities occurring at the site include security, groundwater remediation operations, and environmental monitoring (HDR, 2016). Ongoing site remedial activities are collectively referred to as the Grants Reclamation Project (GRP), and have been ongoing since 1977.

The goal of remediation has been to reduce the concentrations of constituents of concern (COCs) in underlying aquifers to levels meeting designated standards. In general, source and plume control measures have reduced the concentrations of COCs in tailings and the areal extent of observed contaminant plumes. Development of the groundwater models described in this Plan is in support of HMC Mill site closure and assessment of long-term post-closure conditions.

### 1.1.1 Mill Operations and Decommissioning

There were originally two separate mills operated independently on the site, each with separated tailings piles. The larger of the two piles is referred to as the Large Tailings Pile (LTP) and the smaller is referred to as the Small Tailings Pile (STP, Figure 3). Milling operations ceased in February 1990, and the two mills were decommissioned and demolished, with debris buried in place. Demolition activities included removal of asbestos-containing material (ACM), which was disposed of in a pit at the toe of the original slope of the LTP. Mill debris was buried in pits located within the historic mill area or south of the LTP (Figure 3). Slurry grout was used to fill material and voids within the debris pits, which were capped with up to four feet of soil.

Generally concurrent with mill decommissioning, windblown soils with elevated levels of Radium 226 in the near surface were removed and placed in and around the tailings piles. These areas were subsequently covered along with other areas of the site. Cover materials consisting of clean soil and rock were placed on the former mill area, the LTP, and the STP as part of mill decommissioning activities completed in the mid-1990s. After placement of cover materials was completed, drainage areas within the HMC Mill site were regraded and surface channels established for long-term drainage.

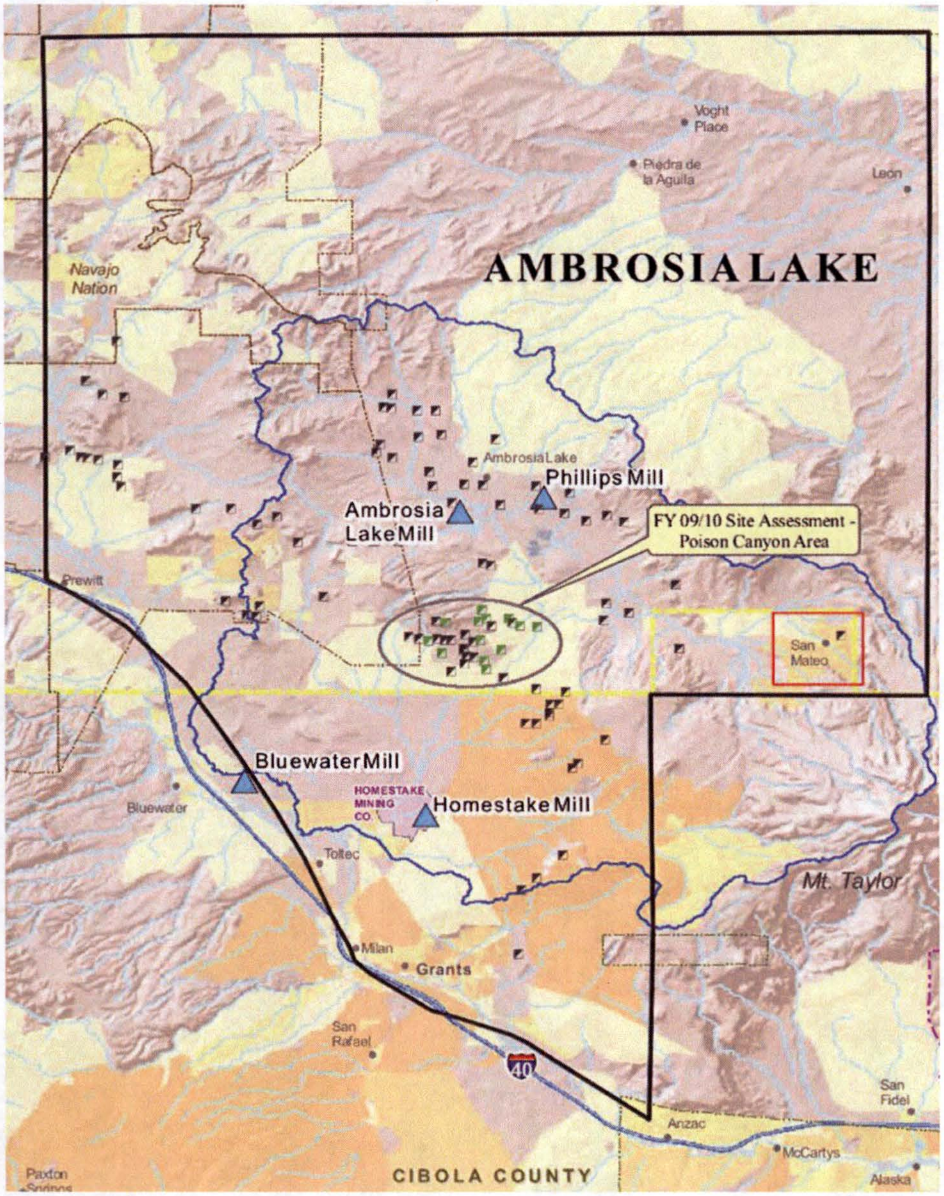


**Figure 1. Site Location Map**

*Source: HDR 2016*

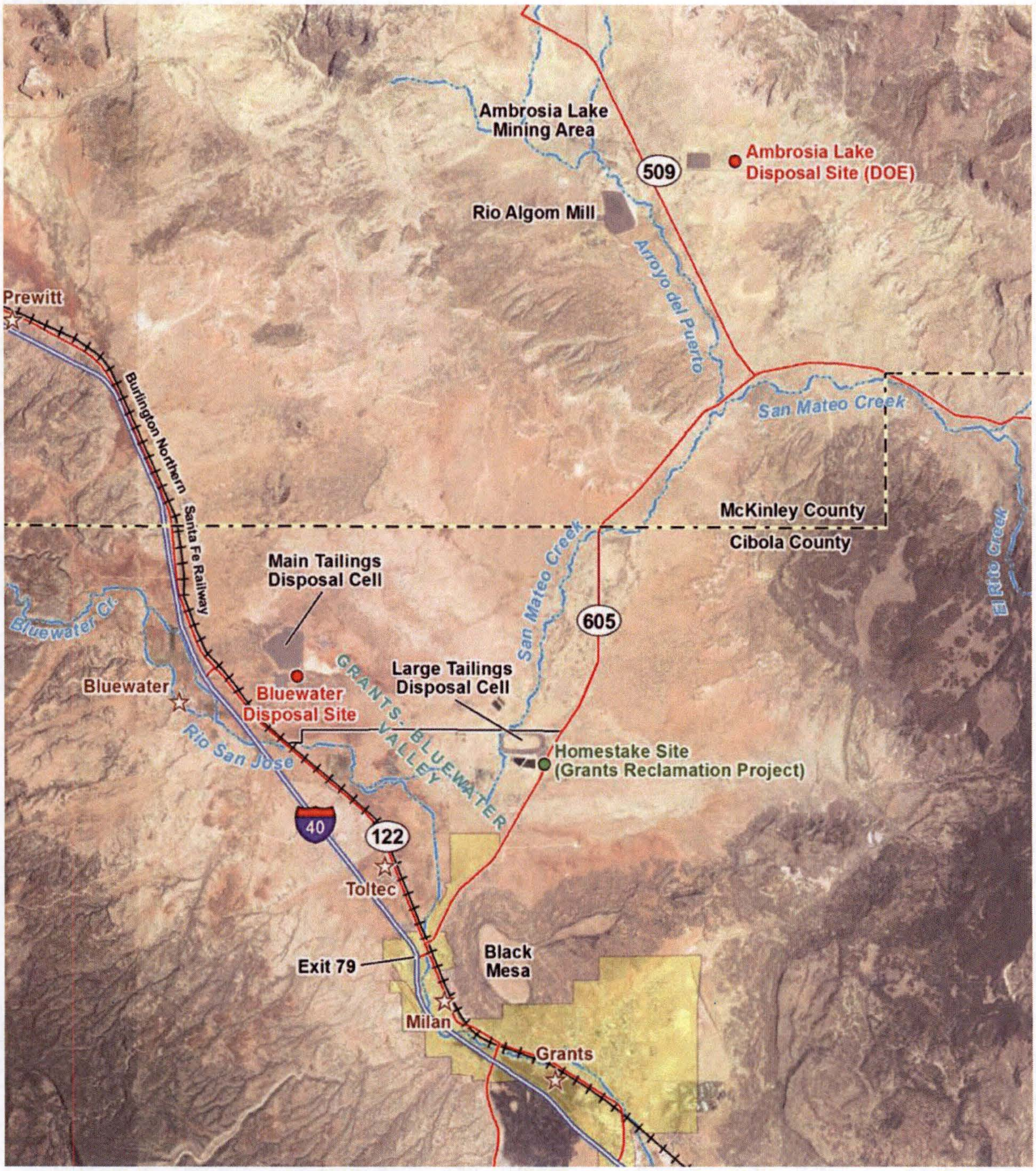


**Figure 2. Location of Historical Uranium Milling Operations**

*Source: U.S. DOE 2014*

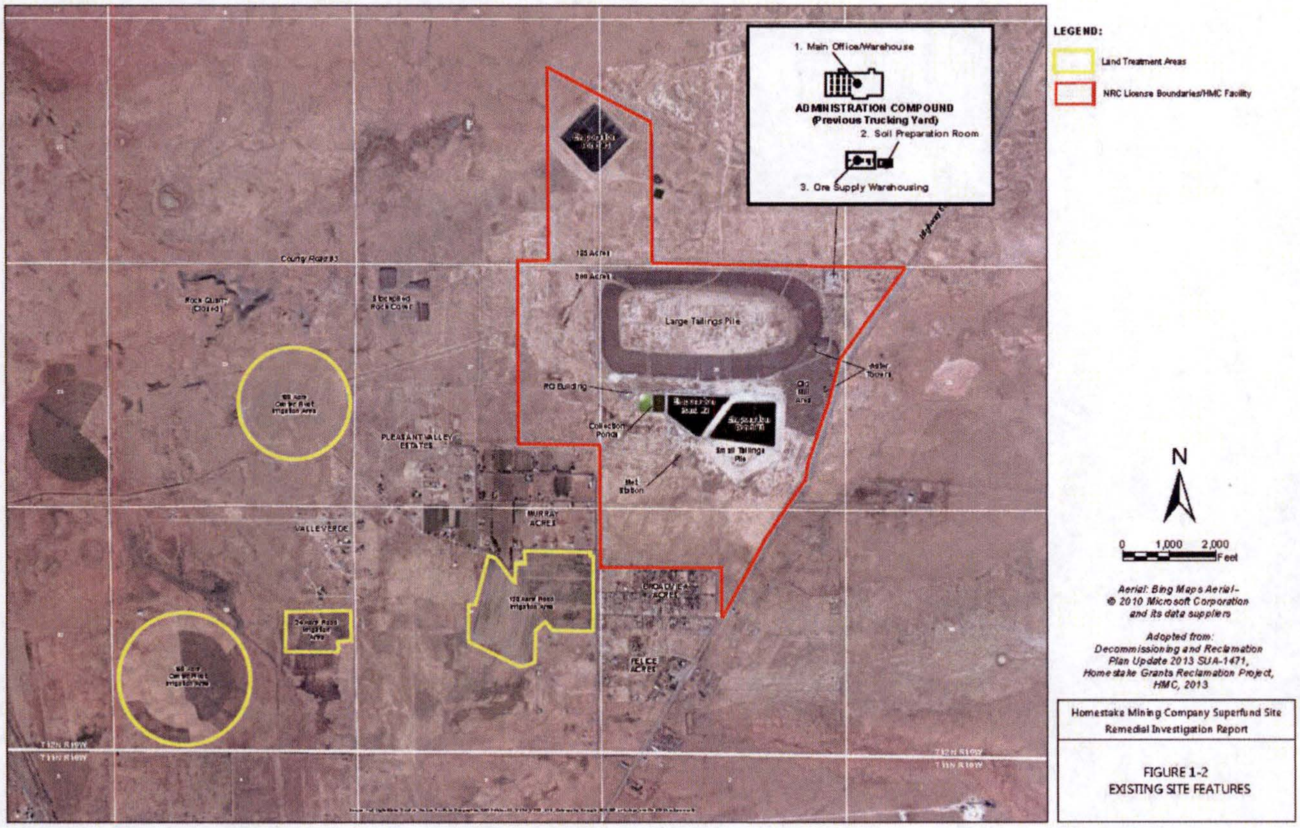


**Figure 3. HMC Mill Site Features**

*Source: HDR, 2016*

### 1.1.2 Groundwater Remediation Activities

In the late 1970s, a contaminant plume was identified originating from seepage from the LTP and moving to the south and west within near-surface alluvium. A system of groundwater wells was installed at that time to create a hydraulic barrier to limit the movement of alluvial aquifer contaminant plume (HDR, 2016). The following is a brief summary of the changes and improvements made to the groundwater remediation system:

- 1977 - 1983—Multiple hydraulic containment and collection wells were installed in the alluvial aquifer.
- 1984—Hydraulic containment of the Upper Chinle aquifer (described in Section 2.1) was initiated.
- 1986—Installation of an extension of the Milan water supply for Broadview Acres, Felice Acres, Murray Acres, and Pleasant Valley Estates subdivisions.
- 1990—Evaporation Pond -1 (EP-1) was constructed within the footprint of the STP to assist in the dewatering of the LTP and to hold water pumped from the collection wells. Additional hydraulic containment and collection wells were installed in the alluvial aquifer.
- 1992—Toe drains were installed around the tailing piles.
- 1993 - 2000—During this period, corrective action and monitoring well networks were revised through addition of new wells and abandonment of certain existing wells.
- 1996—Use of EP-2 began in March.

- 1999—The reverse osmosis (RO) treatment unit was added; treated water is currently used for hydraulic containment of the alluvial aquifer.
- 2000—Irrigation of 270 acres as a means to manage extracted groundwater was initiated.
- 2002—60 acres of irrigation area were added and RO plant capacity increased from 300 gallons per minute (gpm) (one unit) to 600 gpm (two units).
- 2002- Implementation of a tailings flushing program at the LTP to expedite seepage drain down
- 2002-2009—During this period, corrective action and monitoring well networks were revised through addition and abandonment of wells.
- 2004-2005—64 acres of irrigation area were added.
- 2010—EP-3 was constructed and commissioned.
- 2015-Tailings flushing program terminated

Groundwater remediation at the Site is ongoing. The current system includes multiple components that are frequently adjusted based on evaluation of monitoring data. The primary components of the current system are summarized as follows:

- **Hydraulic Containment** - Groundwater extraction from the alluvial, Upper Chinle, and Middle Chinle aquifers (along with groundwater injection) creates a hydraulic barrier to limit the movement of contaminated groundwater. The hydraulic barrier in the alluvial aquifer is created and maintained downgradient of the LTP with dozens of wells used to extract impacted groundwater and to introduce clean water into the alluvium and more than 6,000 linear feet of infiltration lines (HMC, 2012). Water added to the alluvial formation used to create the hydraulic containment area is derived from the RO plant product water, treated effluent from the zeolite pilot testing systems, and the San Andres Glorieta (SAG) aquifer.
- **Groundwater Extraction and RO Treatment** - Groundwater is extracted from numerous dewatering wells and tailing pond toe drains upgradient of the hydraulic barrier created by injected water. Extracted groundwater is routed primarily to the RO treatment plant to remove contaminant mass, or to evaporation ponds if RO capacity is unavailable. RO is the primary treatment process by which constituents of concern (COCs) are removed, along with the zeolite pilot-testing system. Plant influent is composed primarily of groundwater from the alluvial aquifer (approximately 90 percent) and West Collection Pond water (approximately 10 percent), which receives groundwater and tailings water suitable for treatment, along with miscellaneous overflows from the RO plant. As described in the Remedial Investigation report (HDR, 2016), in 2013, approximately 226 gpm of RO plant influent came from the alluvial aquifer collection wells, 22 gpm from the West Collection Pond, and 9.8 gpm from Upper Chinle aquifer extraction wells.
- **Evaporation** - There are three lined evaporation ponds (EP-1, EP-2, and EP-3) in use at the HMC Mill site (Figure 3) that are used for site remediation. The evaporation system is used primarily for brine and water disposal, and receives water from the extraction wells in the alluvial and Upper Chinle aquifers and brine from the RO plant. In 2013, average evaporation from the ponds was approximately 153 gpm, while receiving an average of 78 gpm from the tailings extraction wells, 47 gpm of brine from the RO plant, and 35 gpm from precipitation.

## 1.2 Modeling Objectives

Groundwater flow and transport modeling is proposed for the HMC Mill site and surrounding SMC Basin as a tool to assess historic, current, and potential future changes in groundwater flow and COC transport as a result of ongoing remedial activities performed as part of the GRP. The goal is to develop a single model encompassing the entire SMC Basin that can be used to simulate current GRP groundwater restoration activities and as a tool to predict system changes in response to basin-wide remediation efforts, including an understanding of the long-term fate and transport of constituents of concern.

To efficiently develop a single model for the basin, Site (GRP) and regional (SMC Basin)-scale models will initially be developed separately. BC will develop a detailed model for the GRP while concurrently developing a generalized regional-scale model. The Site-specific model will be developed to support near-term GRP remediation planning for the updated Groundwater Corrective Action Plan, while a more general model of regional conditions is being developed to assess potential basin-wide influences on the HMC Mill site. The principal objectives for the Site-Specific Model include:

- Simulation of groundwater flow and hydraulic heads within the alluvial and bedrock (upper, middle and lower Chinle and San Andres) aquifers beneath the GRP.
- Simulation of fate and transport of site Constituents of Concern (COCs) for the GRP.
- Prediction of remediation time frame for GRP using current groundwater pump and treat methodology.
- If necessary, analysis of remedial alternatives associated with the GRP

The principal objectives for the Regional Model include:

- Simulation of groundwater flow and hydraulic heads for the regional-scale alluvial and bedrock aquifers within the San Mateo Watershed (SMC Basin).
- Simulation of fate and transport of COCs from the Ambrosia Lake area of the SMC Basin.
- Prediction of off-site San Mateo uranium-selenium plume movement towards the GRP.

Once both models have been developed, they can then be merged into a single model that can be used to assess potential effects from historic off-Site mining and milling activities on the HMC Mill Site and potential regional benefits from ongoing remediation activities at the GRP and within the SMC Basin.

Section 2 of this Plan provides a summary of the Regional and Site-Specific Hydrogeology Site Conceptual Models (HSCMs), which will form the basis of numerical model development. Section 3 describes the plan for model development for the Site-Specific (GRP) Model, while the plan for development of the Regional (SMC Basin) Model is outlined in Section 4. Section 5 discusses how the models will be ultimately merged into a single model. Reporting of model results in discussed in Section 6.

# Section 2: Hydrogeologic Site Conceptual Models

Hydrologic site conceptual models (HSCMs) were developed for the both the regional SMC Basin and the HMC Mill Site, and are described in detail in a technical memo (San Mateo Creek Basin and HMC Mill Hydrologic Site Conceptual Models, BC, January 2018), and are briefly summarized here. The site-specific and regional HSCMs form the framework for development of numerical groundwater flow and contaminant transport models covering both regional and site scales. A HSCM is a summary of available knowledge related to groundwater flow and water quality of the principal hydrostratigraphic units at a certain location and scale. The Site and Regional HSCMs describe the current understanding of the following:

- Geologic conditions affecting groundwater flow and water quality, including the influence of geologic structures (e.g., faulting)
- Identification of principal hydrostratigraphic units and aquifers
- Locations and mechanisms of recharge of water to and discharge from principal hydrostratigraphic units and aquifers
- Groundwater flow directions and hydraulic gradients

- Physical properties of hydrostratigraphic units and aquifers, including transmissivity, hydraulic conductivity, and groundwater storage
- Potential for flow interactions between hydrostratigraphic units and aquifers
- Anthropogenic influences on principal hydrostratigraphic units and aquifers (extraction, injection, and water quality impacts) over time

These elements of the HSCMs will form the basis for numerical model development, including the lateral model domain extents, model layer structures, boundary conditions, physical parameterizations, and calibration approaches described in Sections 3 and 4. The Regional and Site HSCMs are summarized in the following sections.

## 2.1 Regional HSCM

Regionally, the SMC Basin is located in the southeastern portion of the Colorado Plateau physiographic province on the south flank of the San Juan Basin. Figure 4 shows the general area in northern New Mexico underlain by the San Juan Basin, while Figure 5 presents a geologic cross-section illustrating the principal stratigraphic units. The region experienced structural deformation during the Laramide Orogeny from near the end of the Late Cretaceous through the Eocene. Uplift associated with this orogeny formed the Zuni Mountains to the southwest of the SMC Basin, which consists of a northwest-trending monoclinal fold dipping northeast into the San Juan Basin. The SMC Basin lies on the eastern flank of the fold, resulting in bedrock and strata that dip to the north-northeast at about 5 to 10 degrees into the San Juan Basin.

Surface geology within the SMC Basin is shown on Figure 6. The primary regional aquifer units in the SMC Basin are as follows (from youngest to oldest):

- Quaternary valley fill deposits (alluvium)
- Menefee Formation
- Point Lookout Sandstone
- Crevasse Canyon Formation
- Gallup Sandstone
- Dakota Sandstone
- Morrison Formation
- Bluff Sandstone
- Entrada Sandstone
- San Andres/Glorieta (SAG) aquifer

The Morrison Formation, Entrada Complex, and SAG are considered the major aquifers in the SMC Basin. Figure 7 presents a geologic cross section through the central portion of the SMC Basin illustrating the aquifer units.

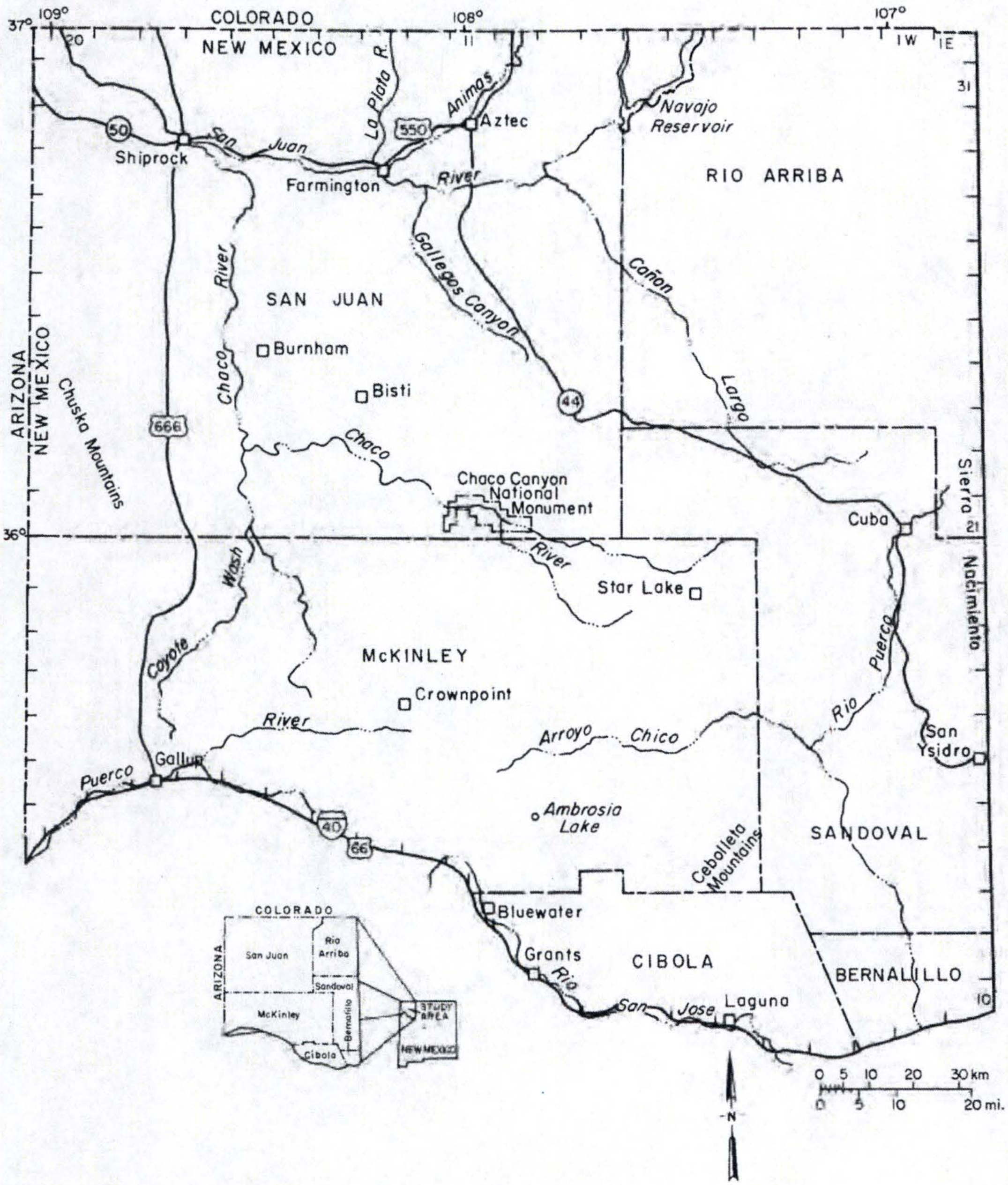


**Figure 4. Geography of Northwest New Mexico Including the San Juan Basin**

*Source: Stone et al. 1983*

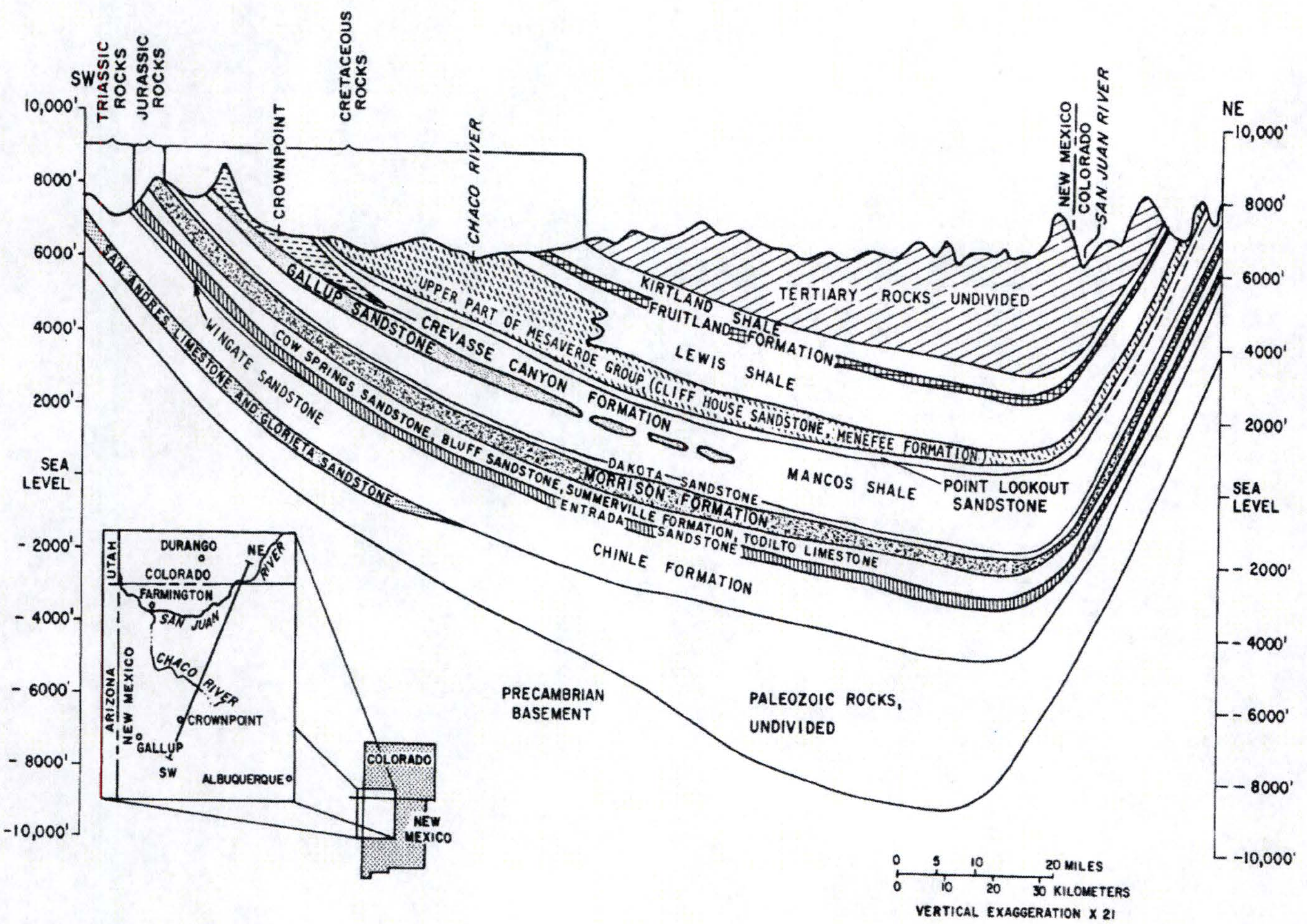


**Figure 5. Regional Geologic Cross Section Through the San Juan Basin**

*Source: Frenzel and Lyford 1982*

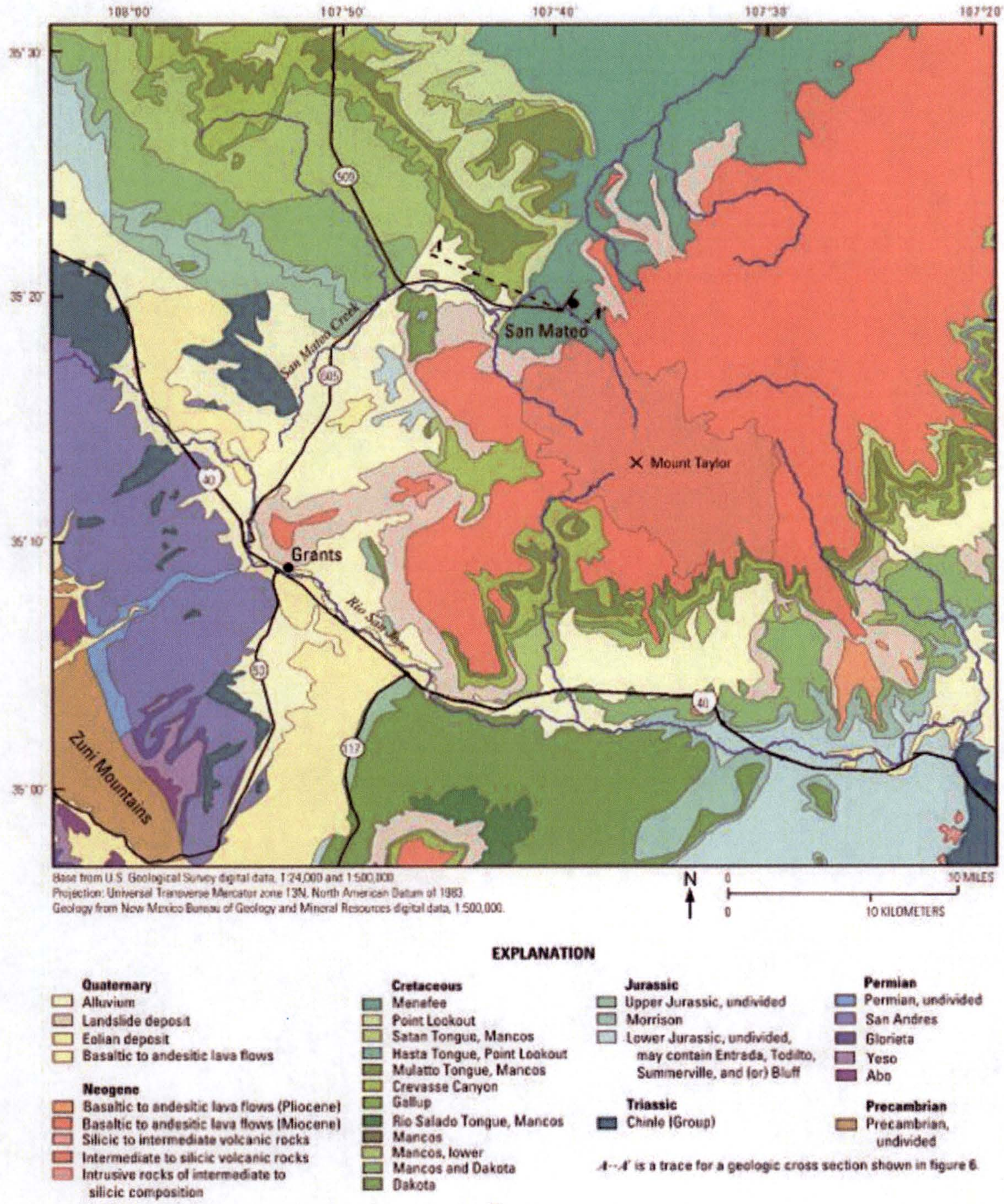


**Figure 6. Surface Geology of the San Mateo Creek Basin**

*Source: Langman et al. 2012*

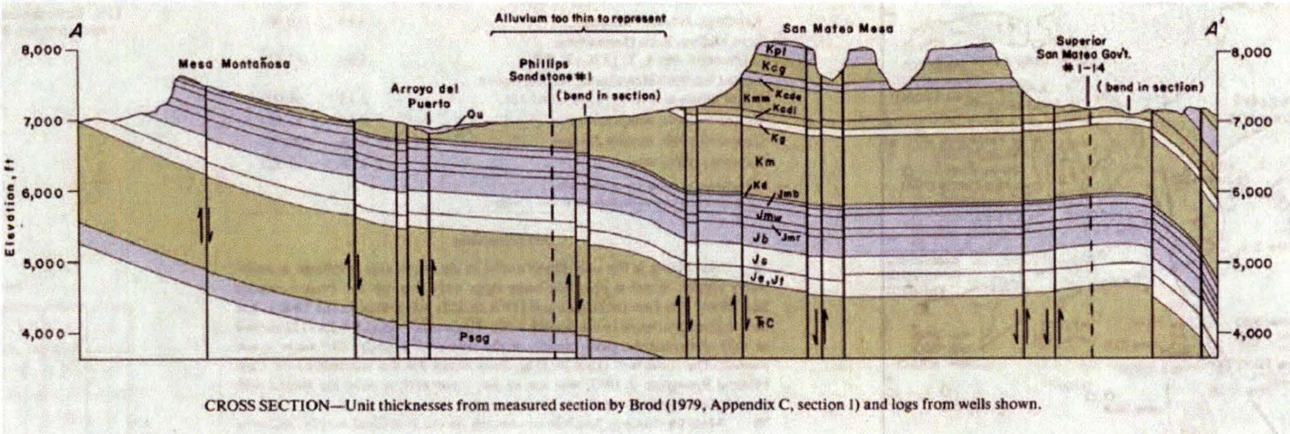


**Figure 7. Hydrogeologic Cross Section Through the San Mateo Basin**

*Source: Brod and Stone 1981*

The SMC Basin is primarily a region of recharge to groundwater, both to shallow and deeper hydrostratigraphic units. Figure 8 shows the general regional groundwater flow patterns for aquifer units that receive recharge within the SMC Basin. Groundwater recharge, discharge, and flow characteristics as well as aquifer physical properties for each of the principal aquifers in the SMC Basin are provided as part of the Regional HSCM (BC, 2018). The effects of groundwater extraction in the alluvial, Morrison Formation, and SAG aquifer on regional flow conditions are also presented. The main structural features in the SMC Basin consist of north- to northeast-trending sub-vertical normal faults, which may locally either impede or facilitate groundwater flow, depending on orientation and offset.

Mining activities have affected groundwater quality in alluvium and bedrock aquifers in the vicinity of the four mill sites. In the Ambrosia Lake area, direct discharge and surface infiltration of mine dewatering flows and from unlined evaporation ponds has resulted in elevated concentrations of constituents in alluvial groundwater, including sulfate, uranium, radium, gross alpha emissions, total dissolved solids (TDS), and selenium (U.S. EPA, 2016). Concentrations of these constituents have exceeded federal drinking water standards in both alluvial groundwater and within underlying bedrock units downgradient of historical mining and mill sites in the Ambrosia Lake area.

Activities at the Bluewater Mill site affected groundwater within both alluvium associated with the Rio San Jose and the underlying SAG aquifer (U.S. DOE, 2014). Elevated levels of molybdenum, selenium, and uranium have been detected downgradient of the Bluewater Mill site and historical tailings pond. Uranium has been identified as the primary constituent of concern, and uranium concentrations above the federal drinking water standard have been observed downgradient of the site.

Key elements of the Regional HSCM for the SMC Basin are summarized as follows:

- The SMC Basin is located at the southern margin of the San Juan Basin.
- Aquifers of Quaternary, Cretaceous, Jurassic, and Permian age units are present in the SMC Basin.
- Principal regional aquifers that may have significant flow in the SMC Basin include the alluvium, Menefee, Point Lookout, Gallup, Morrison, and SAG aquifers.
- Geologic uplift of the Zuni Mountains on the southwest edge of the SMC Basin has exposed outcrops of the principal aquifers. Aquifer units generally dip to the north-northeast toward the central portion of the San Juan Basin.

- Flow directions in the Cretaceous and Jurassic aquifers are variable but generally toward the east-northeast from outcrops and subcrops in the SMC Basin toward discharge to the Rio Puerco watershed.
- Groundwater flow in the Permian SAG aquifer is generally to the east, with local discharge via upward flow to alluvium of the Rio San Jose.
- Hydraulic conductivities and other aquifer parameters typically vary greatly between units, vertically within many units, and even aerially within some units in the basin.
- Historical groundwater pumping has occurred primarily in the alluvium, Morrison, and SAG aquifers.
- Extensive pumping from the Morrison Formation in the Ambrosia Lake area between the late 1950s and early 1980s resulted in significant water level declines in the aquifer. Water levels in this area are recovering after the cessation of pumping, but few water-level data are available to evaluate system recovery.
- Groundwater pumped from the Morrison Formation for dewatering of uranium mines was discharged into local drainages including Arroyo del Puerto. This discharge provided significant recharge to previously unsaturated alluvium, and this water still persists in the alluvial system.
- The SAG aquifer represents the primary regional source of groundwater. Extensive pumping from the aquifer has occurred since the 1940s for irrigation, municipal, and industrial uses.
- Long-term pumping in the SAG aquifer has produced local-scale and regional-scale drawdowns in the aquifer.
- In general, there is little evidence of inter-aquifer flow in the basin, which is due to the presence of low-permeability aquitards between the principal aquifers.
- High-angle normal faulting has locally affected groundwater flow, including near the Bluewater and HMC Mill sites, where local faulting has been shown to restrict groundwater flow.
- Mining and milling activities within the SMC Basin have impacted both local- and regional-scale groundwater quality.

These elements of the HSCM will be translated into the regional flow model as described in Section 4.

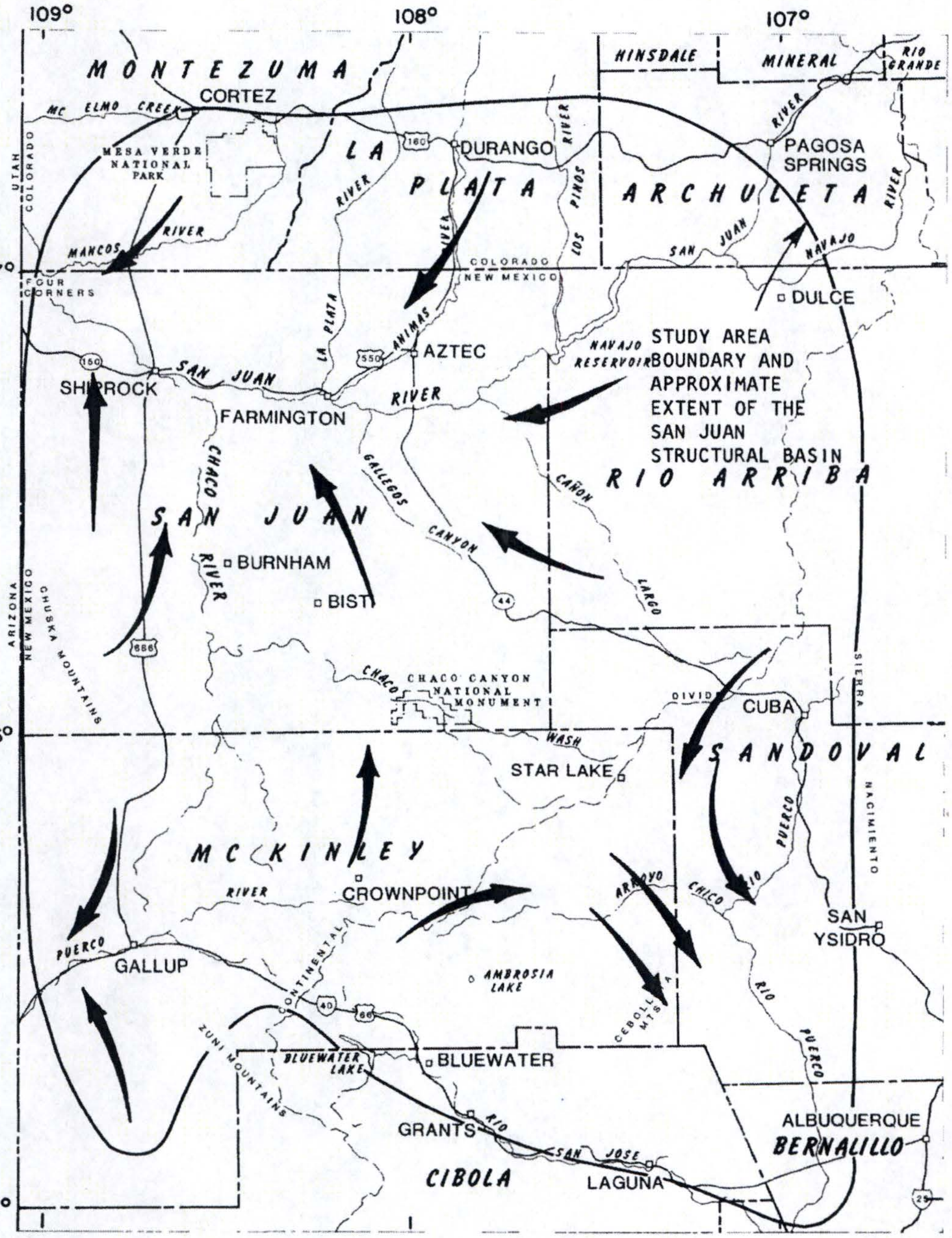


**Figure 8. Conceptual Groundwater Flow Directions in Cretaceous and Jurassic Aquifers**

*Source: Frenzel and Lyford 1982*

## 2.2 HMC Mill Site HSCM

As previously mentioned, the HMC Mill site lies in the southernmost (lower) portion of the SMC Basin (Figure 1). The site currently consists of partially reclaimed tailings piles, buried (i.e., reclaimed) mill debris, RO remediation system, wells and evaporation ponds related to ongoing active groundwater restoration (Figure 3).

The following four geologic units are present at the HMC Mill site:

- Alluvium
- Chinle Formation
- San Andres Limestone
- Glorieta Sandstone

Figures 9, 10, and 11 present geologic cross sections through the site illustrating the principal aquifers and the influence of local fault structures. The aquifer units are summarized as follows:

- Quaternary alluvium underlies the entire site, has variable hydraulic characteristics based on extensive testing, and is generally 50 to 100 feet thick.
- The Chinle Formation is up to 900 feet thick at the site. Although the Chinle is dominated by low-permeability shale units, beneath the site it contains three water-bearing units of relatively higher permeability. These water-bearing units are referred to as the Upper Chinle Sandstone, Middle Chinle Sandstone, and Lower Chinle Mudstone.
- The lowermost units of interest at the site are the San Andres Limestone and Glorieta Sandstone, which together are 200 to 225 feet thick. The SAG is overlain by an unconformity and underlain by the lower-permeability Yeso and Abo formations.

As shown on Figures 9 through 11, the sedimentary rock units at the site dip gently to the east-northeast, following the regional dip of these units. Pre-Quaternary deformation and erosion has resulted in sedimentary rock units that subcrop beneath the alluvium at the site.

Two north-northeast-trending normal faults are present at the site, known as the East Fault and West Fault (Figure 12). These faults are approximately vertical and down-dropped on the east. The vertical displacements of the faults have juxtaposed the more permeable units of the Chinle Formation against less permeable mudstone layers, thus affecting the local flow regime. The San Andres Limestone and Glorieta Sandstone, although vertically displaced, maintain horizontal connectivity across the faults and flow is not affected.

### 2.2.1 Alluvial Aquifer

The alluvial aquifer is the principal unit of interest at the HMC Mill Site. The alluvial aquifer is unconfined with saturated thickness ranging from zero to approximately 70 feet and is composed of three connected alluvial systems: SMC, Lobo Canyon drainage, and Rio San Jose (HDR, 2016). The SMC alluvium composes the north/northeastern branch and the central portion of the alluvial aquifer beneath the site, the Rio Lobo alluvium forms the eastern/southeastern branch of the alluvial aquifer, and the Rio San Jose alluvium forms the west-southwest portion of the alluvial aquifer. A local bedrock high causes the alluvial aquifer to branch to the west and south before the SMC and Rio Lobo alluvial systems converge with the Rio San Jose alluvium.

The alluvial aquifer at the HMC Mill site is recharged from (1) upgradient inflows from the upper and middle SMC basin, (2) surface streamflow infiltration losses and precipitation that collects in low-lying areas, (3) continued drain down of the Large Tailings Pile, (4) injection of treated groundwater and SAG groundwater via the site remediation system, and (5) discharge from the underlying Chinle and SAG aquifers at subcrops where heads in these aquifers are higher than alluvial aquifer heads. Discharge from the alluvial aquifer occurs via (1) pumping of contaminated groundwater to the treatment plants, (2) discharge to the underlying

Chinle and SAG aquifers at subcrops where heads in the alluvial aquifer are higher than heads in these aquifers, and (3) groundwater outflow downgradient (south) of the HMC Mill site. Groundwater levels and flow directions within the alluvium are shown on Figure 13.

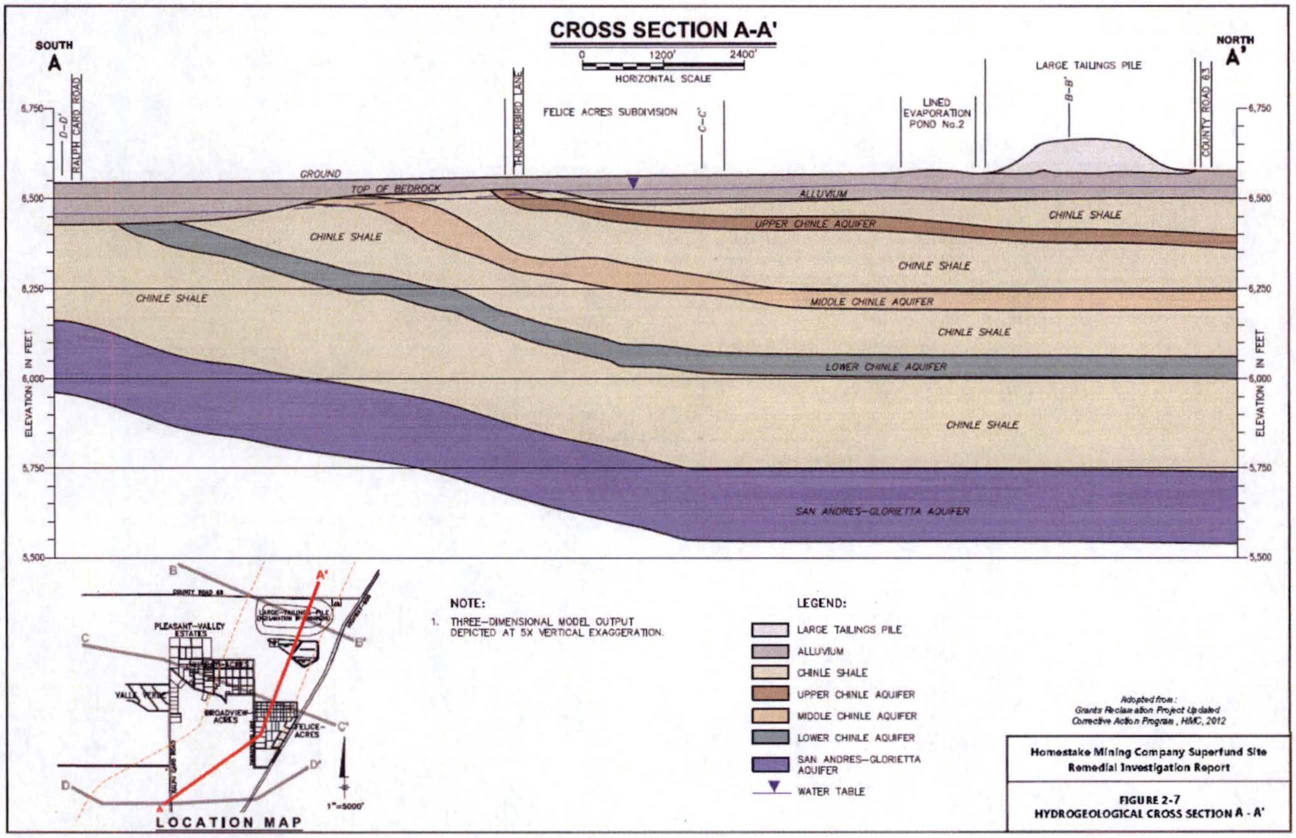


**Figure 9. Cross-Section A-A' at HMC Mill Site**

*Source: HDR 2016*

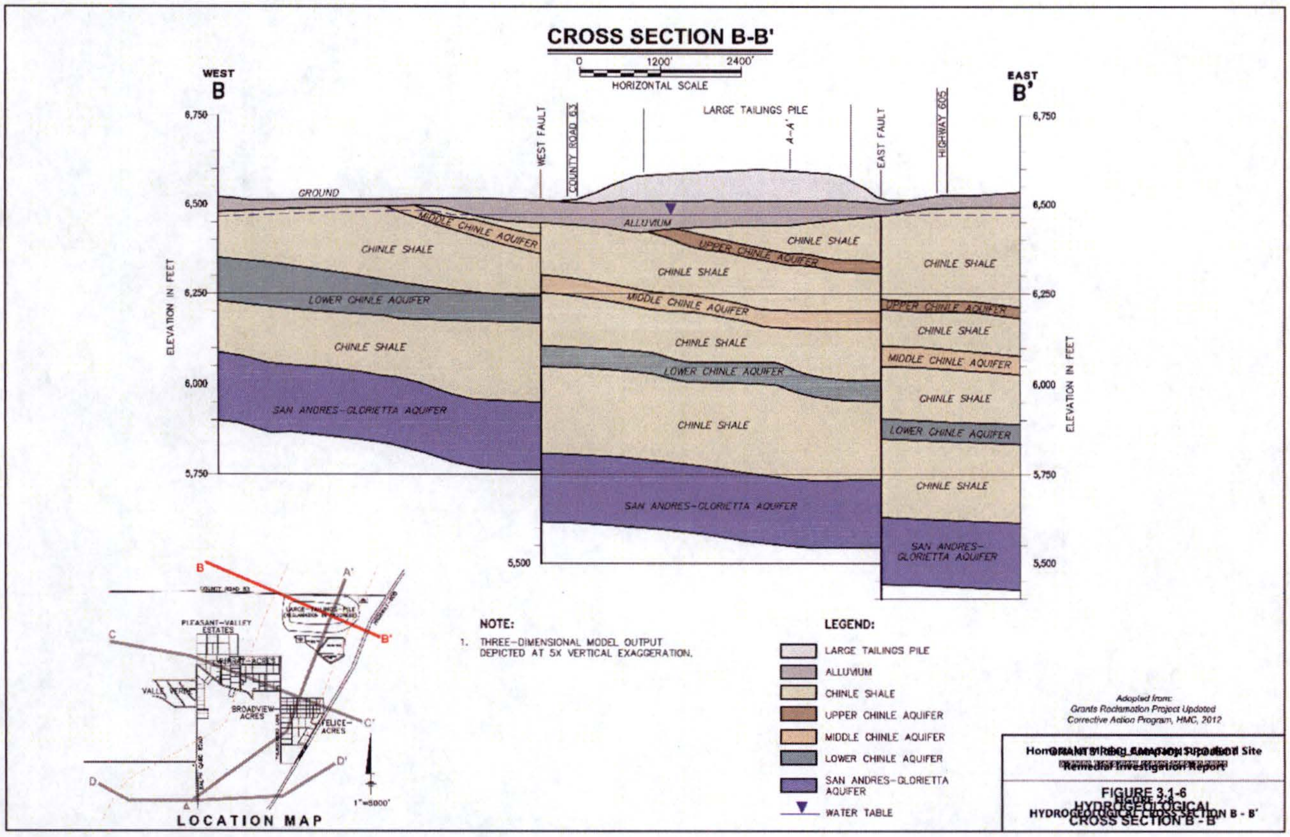


**Figure 10. Cross Section B-B' Showing Fault Offsets at HMC Mill Site**

*Source: HDR 2016*

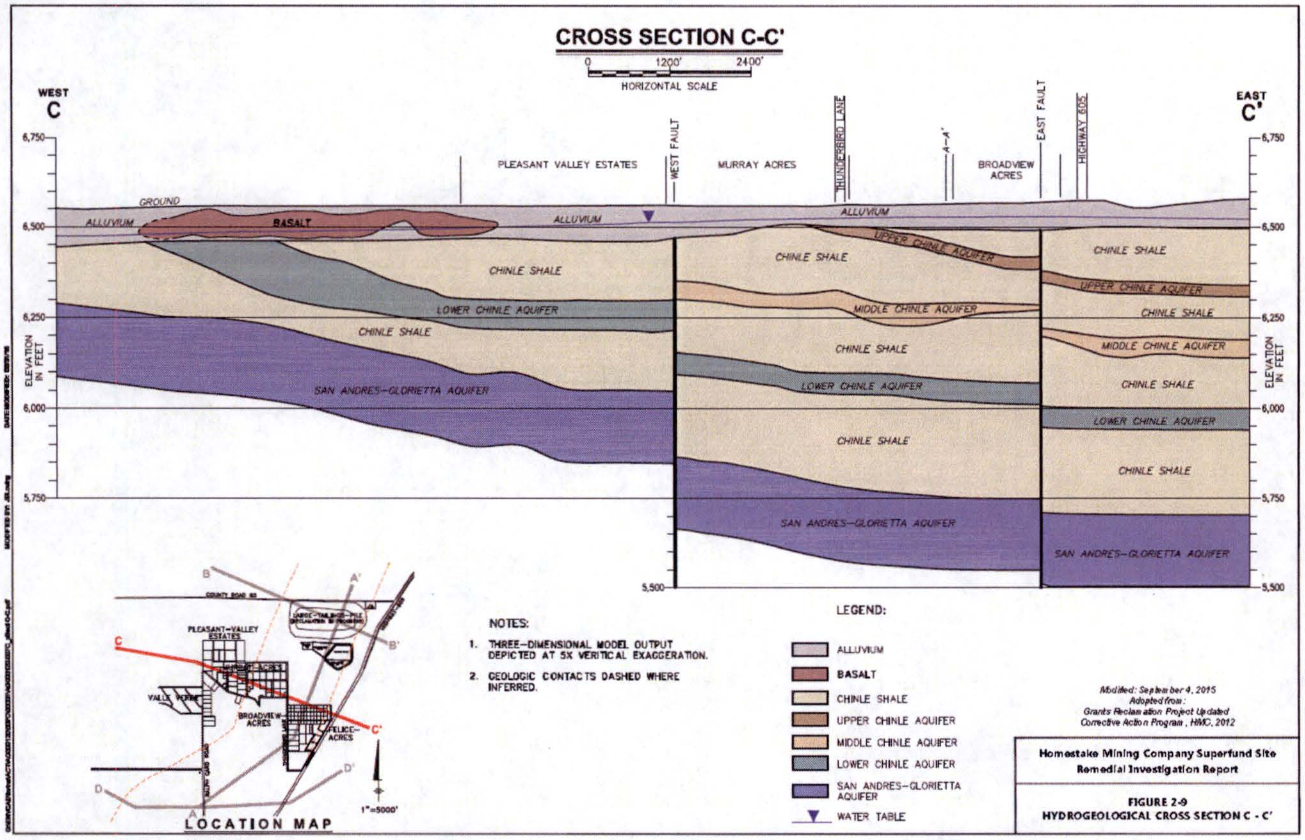


**Figure 11. Cross Section C-C' Showing Interbedded Quaternary Basalt Flow**

*Source: HDR 2016*

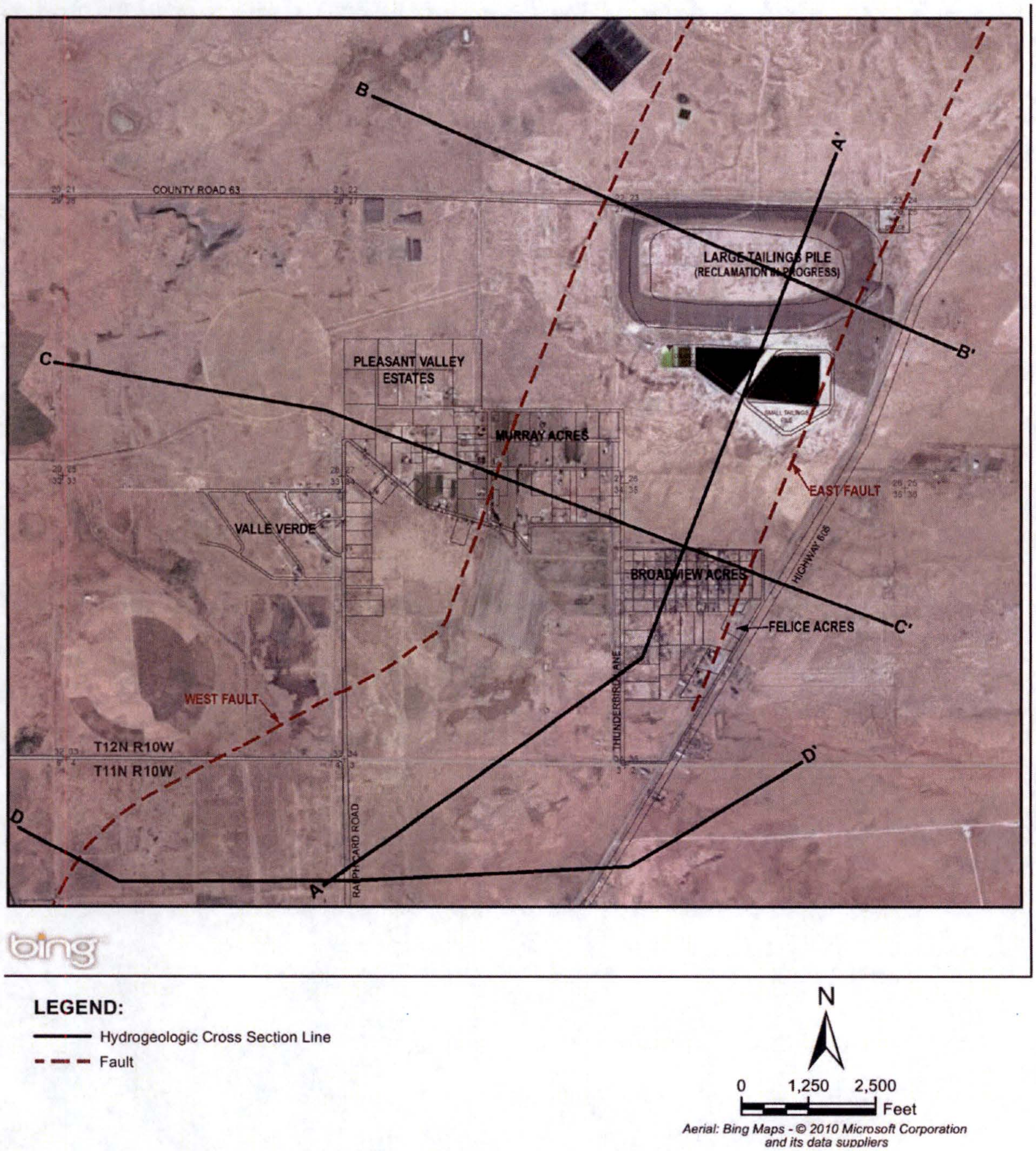


**Figure 12. Faults Mapped at HMC Mill Site**

*Source: HDR 2016*

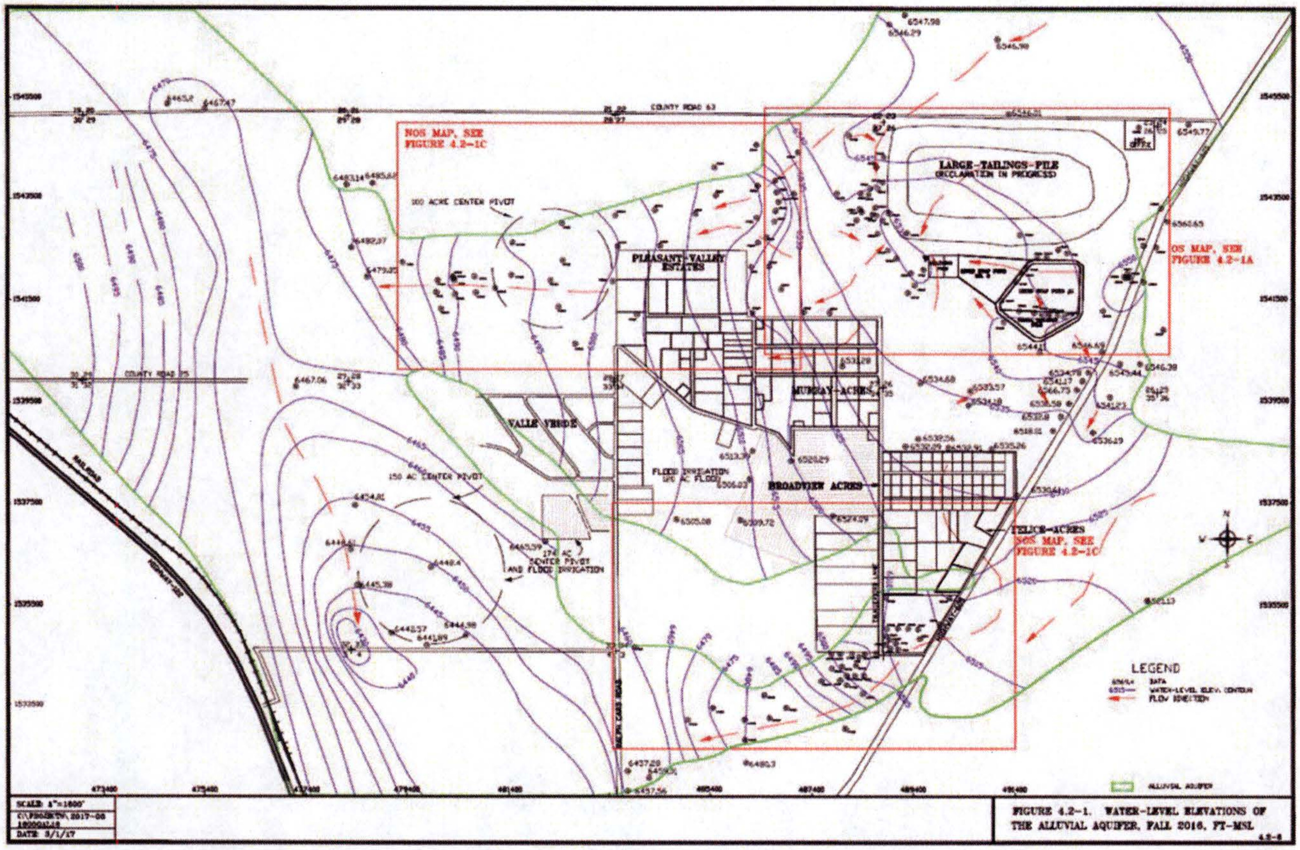


**Figure 13. Alluvial Aquifer Groundwater Elevations and Flow Directions**

*Source: Hydro-Engineering, LLC 2017*

### 2.2.2 Chinle Aquifers

The Chinle Formation in the vicinity of the HMC Mill site includes three water-bearing permeable sandstone horizons separated by shale, referred to as the Upper, Middle, and Lower Chinle aquifers. These aquifers are generally confined. The Chinle aquifers are generally recharged from (1) injection of treated groundwater and SAG groundwater via the site remediation system operations and (2) recharge from the overlying alluvial aquifer at subcrops where alluvial heads are greater than heads in the Chinle aquifers. Discharge from the Chinle aquifers occurs via (1) pumping of contaminated groundwater to the treatment plants, (2) discharge to the overlying alluvial aquifer at subcrops where heads in the Chinle aquifers are higher than alluvial heads, and (3) groundwater flow generally downdip away from the Site to east-southeast. Groundwater levels and flow directions for the Chinle aquifers are shown on Figures 14, 15, and 16.

### 2.2.3 SAG Aquifer

The SAG aquifer has a thickness exceeding 200 feet near the HMC Mill site and is the most significant regional aquifer in the area (HDR, 2016). As previously noted, the East and West faults do not displace the San Andres Limestone and Glorieta Sandstone enough to cause a lateral discontinuity. The SAG aquifer at the HMC Mill site is recharged from the overlying alluvial aquifer at subcrops where alluvial heads are greater than heads in the SAG. These subcrops are located to the west of the GRP in the area of the former Bluewater Mill site. Injection from the site remediation system is not occurring in the SAG. Discharge from the SAG aquifer occurs via (1) pumping of groundwater as a source of fresh water for use in the treatment plants' hydraulic containment system in the alluvial and Chinle aquifers, (2) discharge to the overlying alluvial aquifer at subcrops where heads in the SAG aquifer are higher than alluvial heads, and (3) groundwater outflow to the east-southeast. In the vicinity of the site, the primary interaction between the SAG and alluvial aquifers appears to be recharge of the SAG aquifer from the overlying alluvium, as evidenced by higher alluvial heads compared to SAG heads near the SAG subcrop.

Water-level elevations and generalized flow directions for the SAG aquifer at the HMC Mill site in Fall 2016 are shown on Figure 17. The ambient flow direction in the SAG aquifer is to the east-southeast.

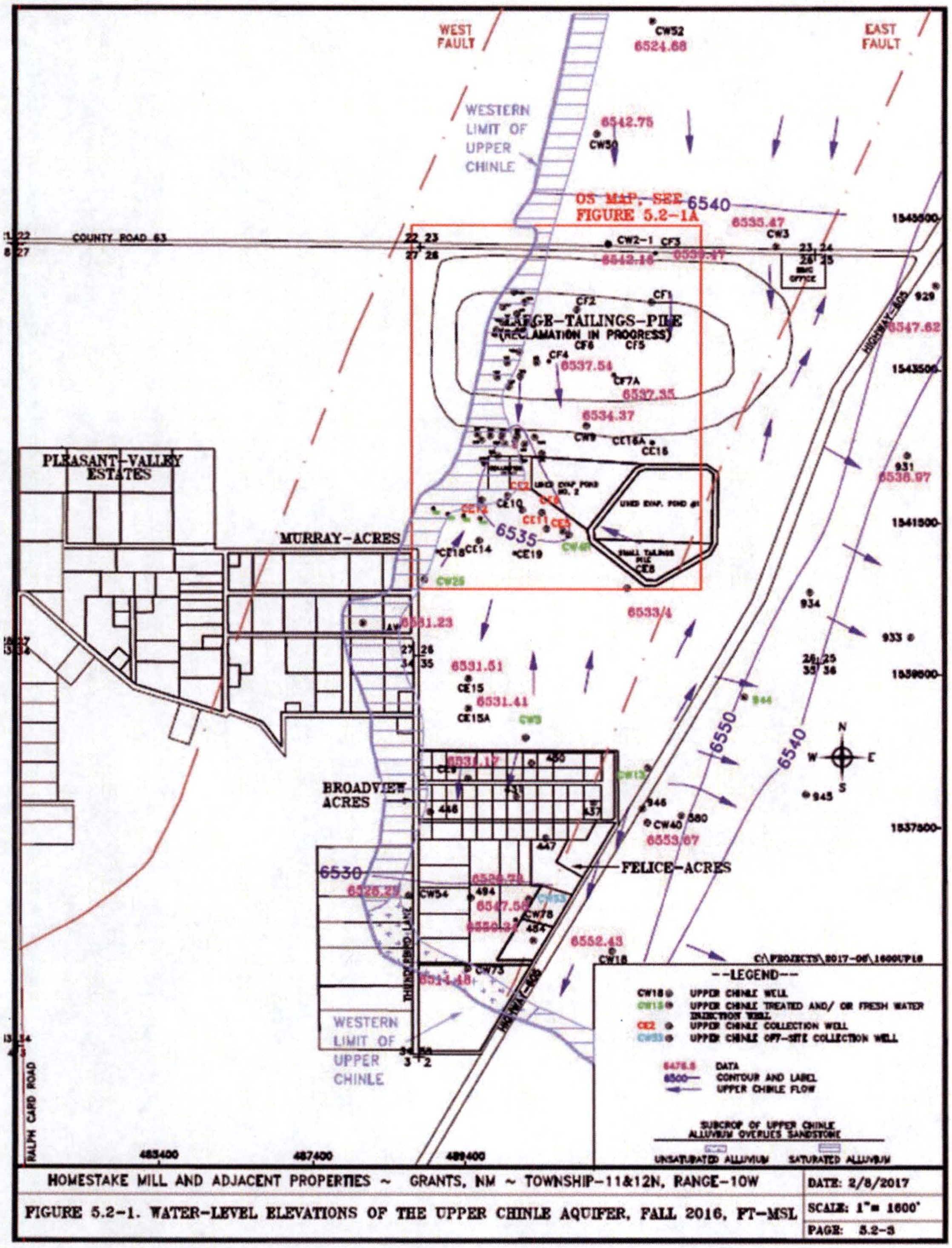


**Figure 14. Upper Chinle Aquifer Groundwater Elevations and Flow Directions**

*Source: Hydro-Engineering, LLC 2017*

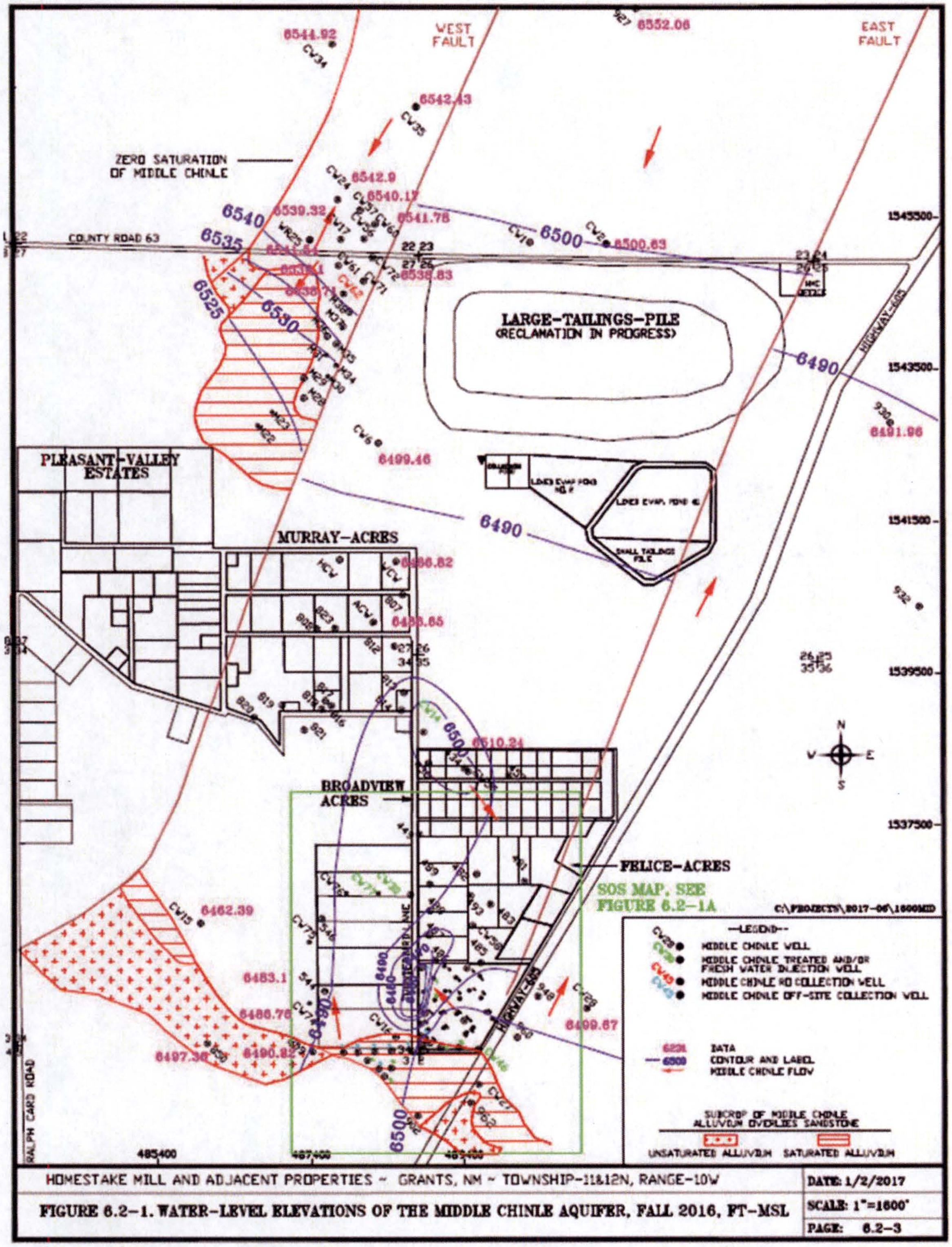


**Figure 15. Middle Chinle Aquifer Groundwater Elevations and Flow Directions**

*Source: Hydro-Engineering, LLC 2017*

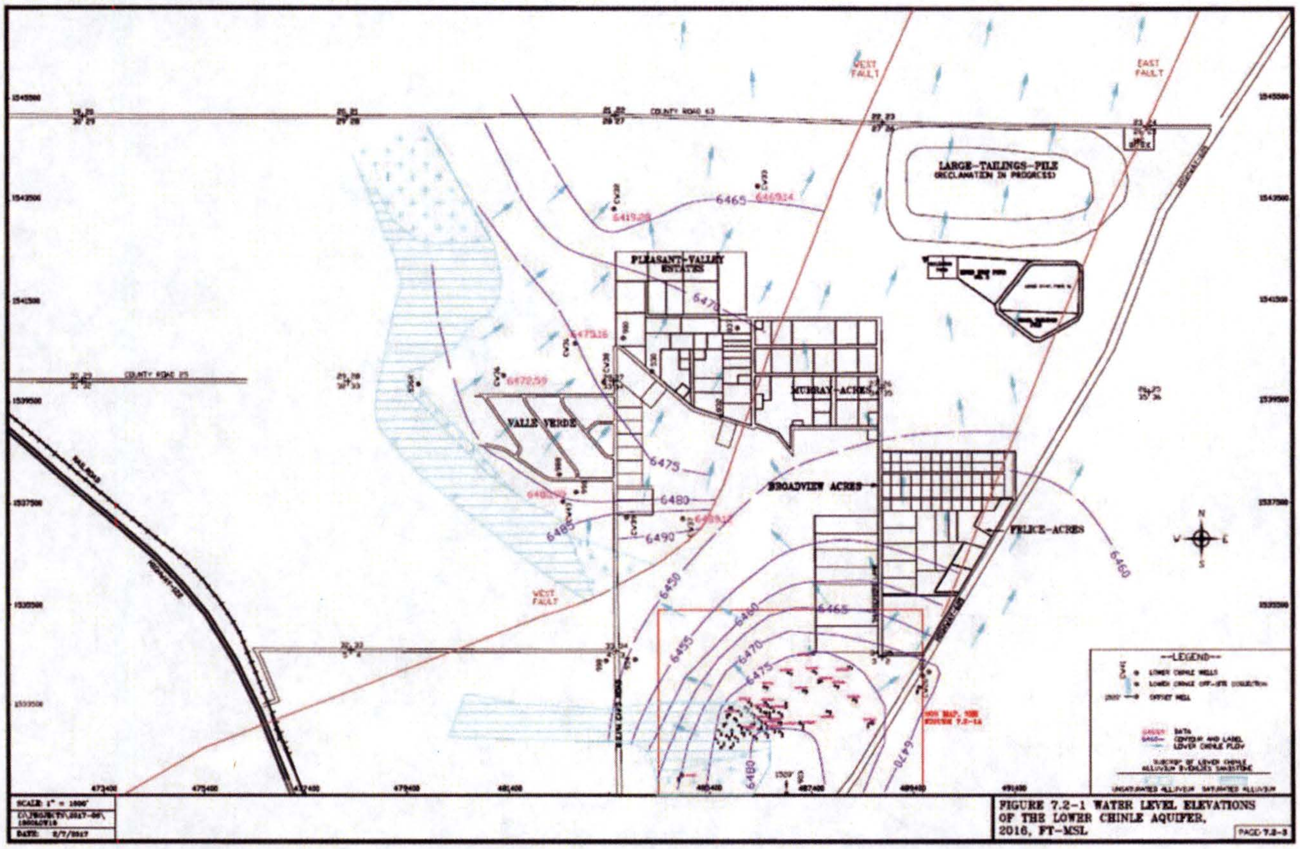


**Figure 16. Lower Chinle Aquifer Water Levels and Flow Directions**

*Source: Hydro-Engineering, LLC 2017*

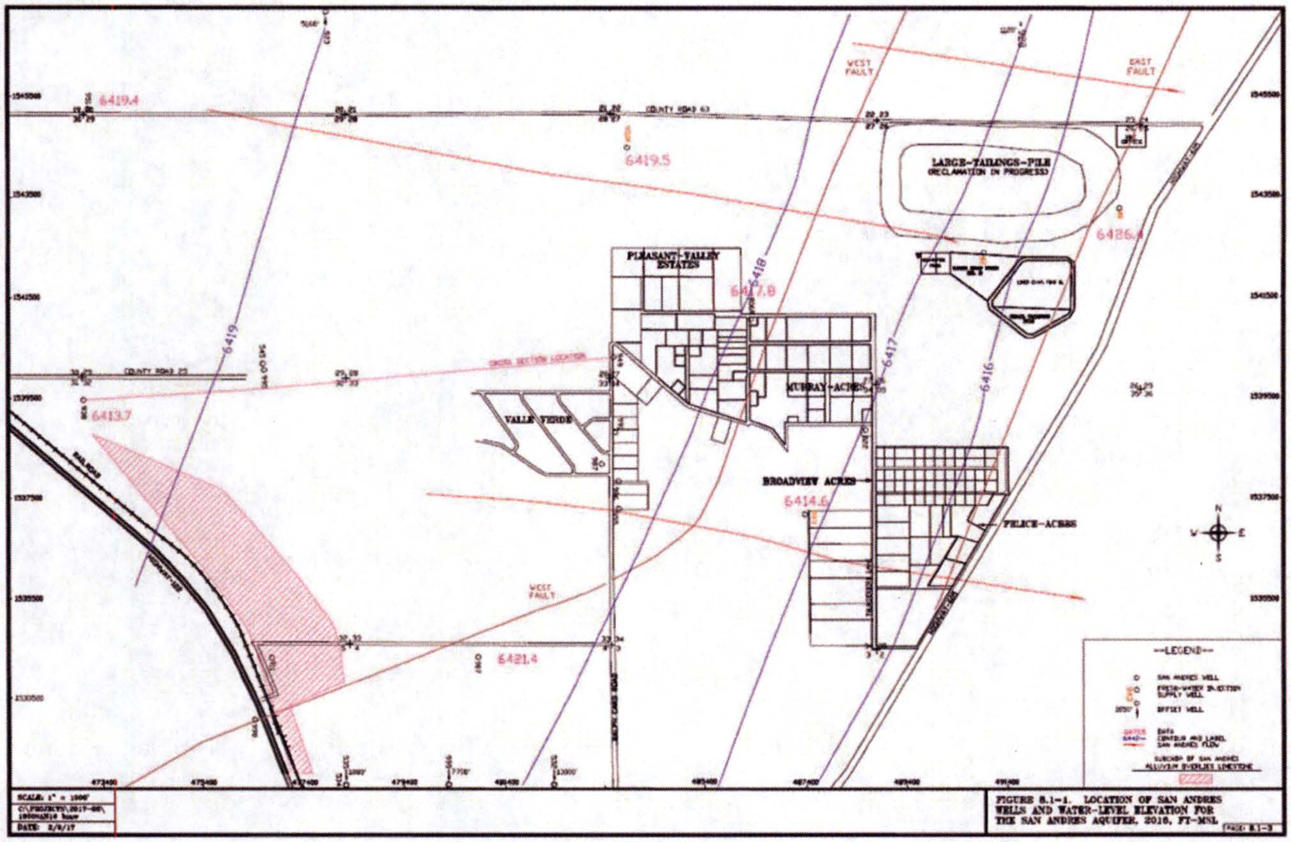


**Figure 17. SAG Aquifer Groundwater Elevations and Flow Directions**

*Source: Hydro-Engineering, LLC 2017*

## 2.2.4 Extent of Contamination

The primary sources of groundwater contamination at the HMC Mill site are the Large and Small Tailings Piles (HDR 2016). Historical seepage of process-water-bearing uranium and other trace radioactive and non-radioactive constituents resulted in loading of these metals to alluvial groundwater beneath the tailings piles. The extent of contamination in the alluvial and Chinle aquifers at the end of 2016, based on uranium concentrations exceeding the current site standards (NRC License Site Background Cleanup levels, as discussed in HDR 2016), is shown on Figures 18 through 21. Groundwater contamination from the HMC Mill site has not been detected in the SAG aquifer. Substantial progress in reducing constituent concentrations has been made in the alluvial and Chinle water-bearing zones since remediation activities began in the 1980s.

In the alluvial aquifer, groundwater concentrations exceed uranium site standards (1) beneath the tailings piles, (2) in western and southern plumes emanating from the tailings pile area, and (3) in an apparently isolated plume south of Felice Acres resulting from continuity with impacted groundwater in the LTP area through the Upper Chinle aquifer and possibly through the alluvium. (Figure 18).

In the Upper Chinle aquifer, groundwater concentrations exceed the uranium site standards (1) beneath the tailings piles and (2) near Broadview and Felice Acres (Figure 19).

In the Middle Chinle aquifer, groundwater concentrations exceed uranium site standards (1) near the subcrop west of the West Fault and (2) near Broadview and Felice Acres (Figure 20).

In the Lower Chinle aquifer, groundwater concentrations exceed uranium site standards near the subcrop south of Felice Acres (Figure 21).

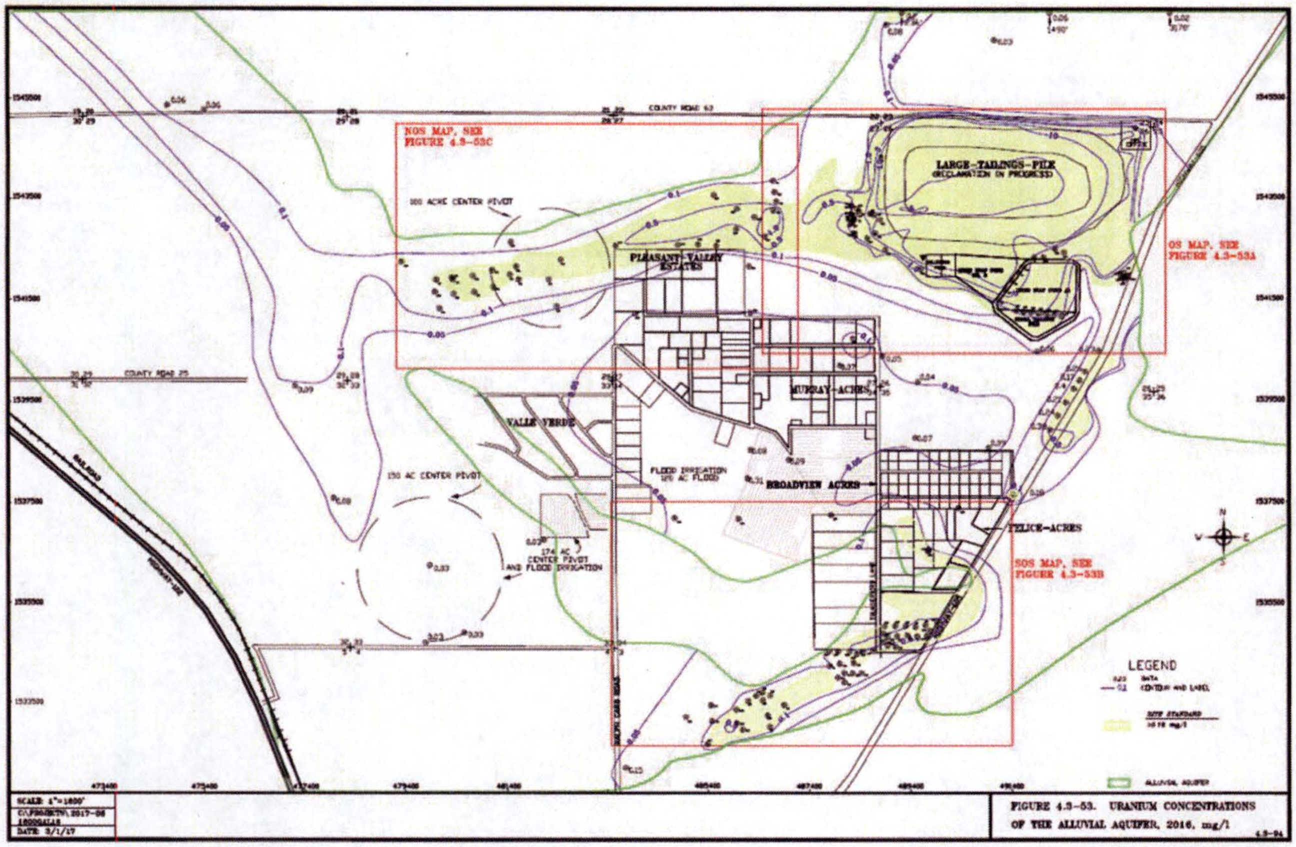


**Figure 18. Extent of Uranium Contamination in the Alluvial Aquifer**

*Source: Hydro-Engineering, LLC 2017*

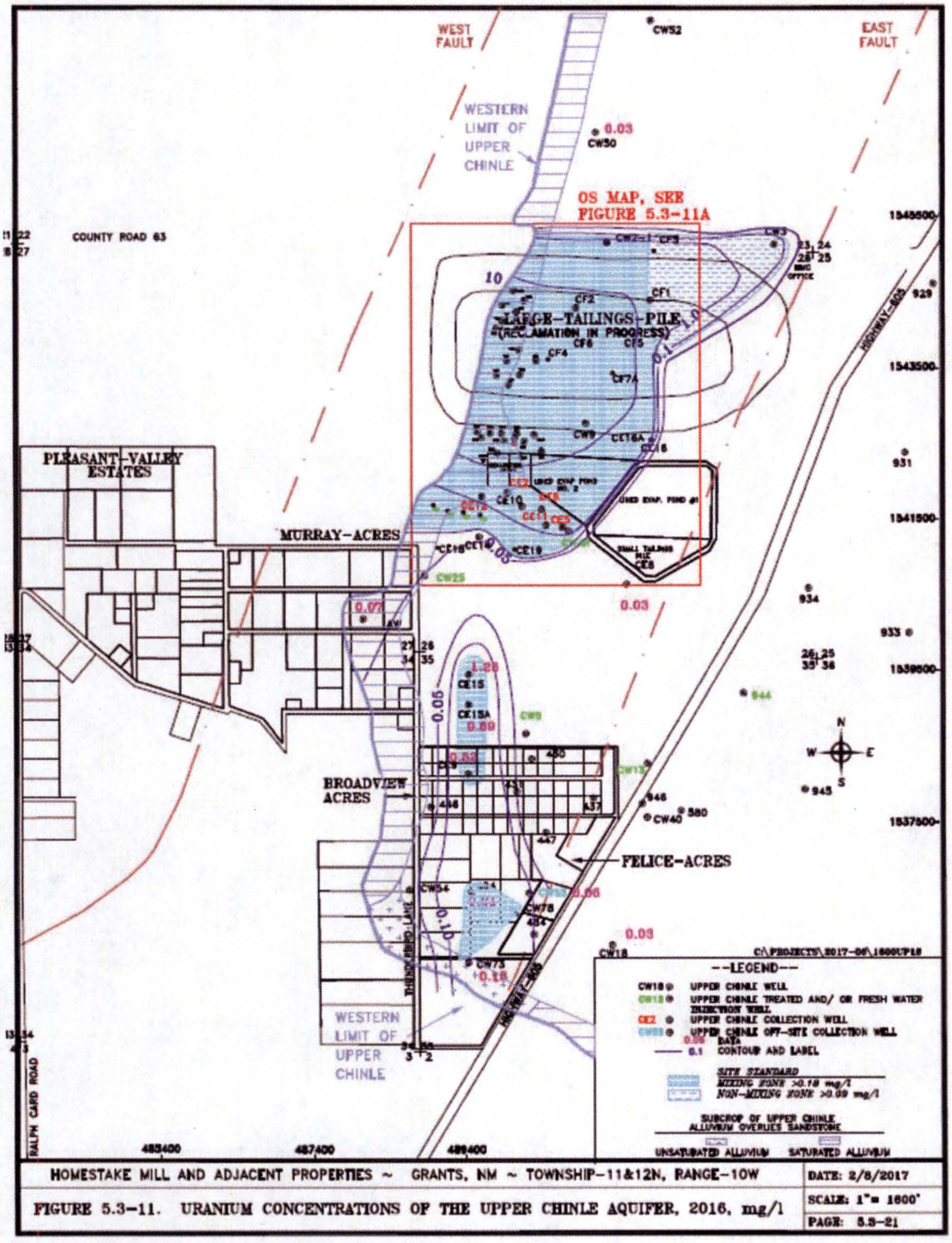


**Figure 19. Extent of Uranium Contamination in the Upper Chinle Aquifer**

*Source: Hydro-Engineering, LLC 2017*

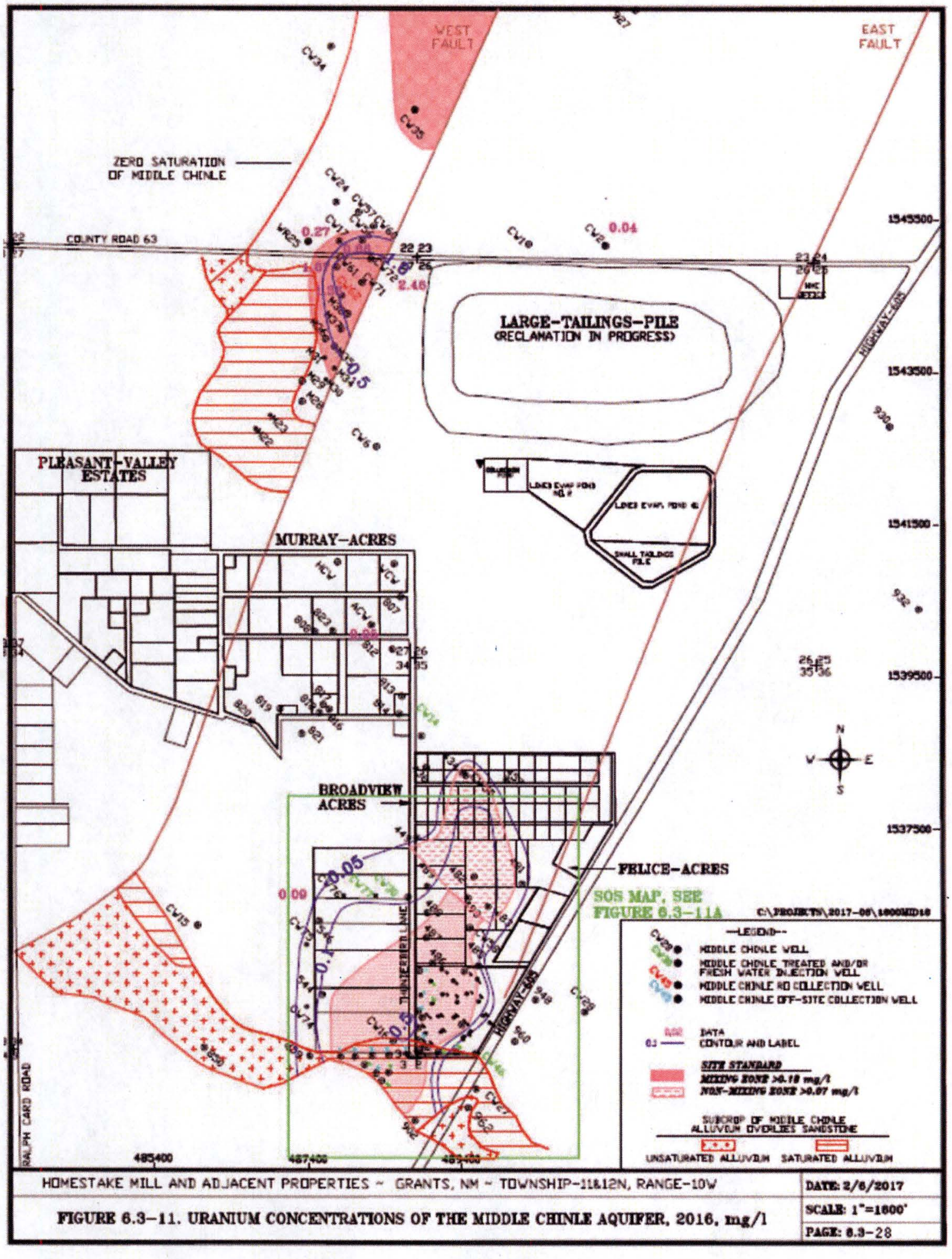


**Figure 20. Extent of Uranium Contamination in the Middle Chinle Aquifer**

*Source: Hydro-Engineering, LLC 2017*

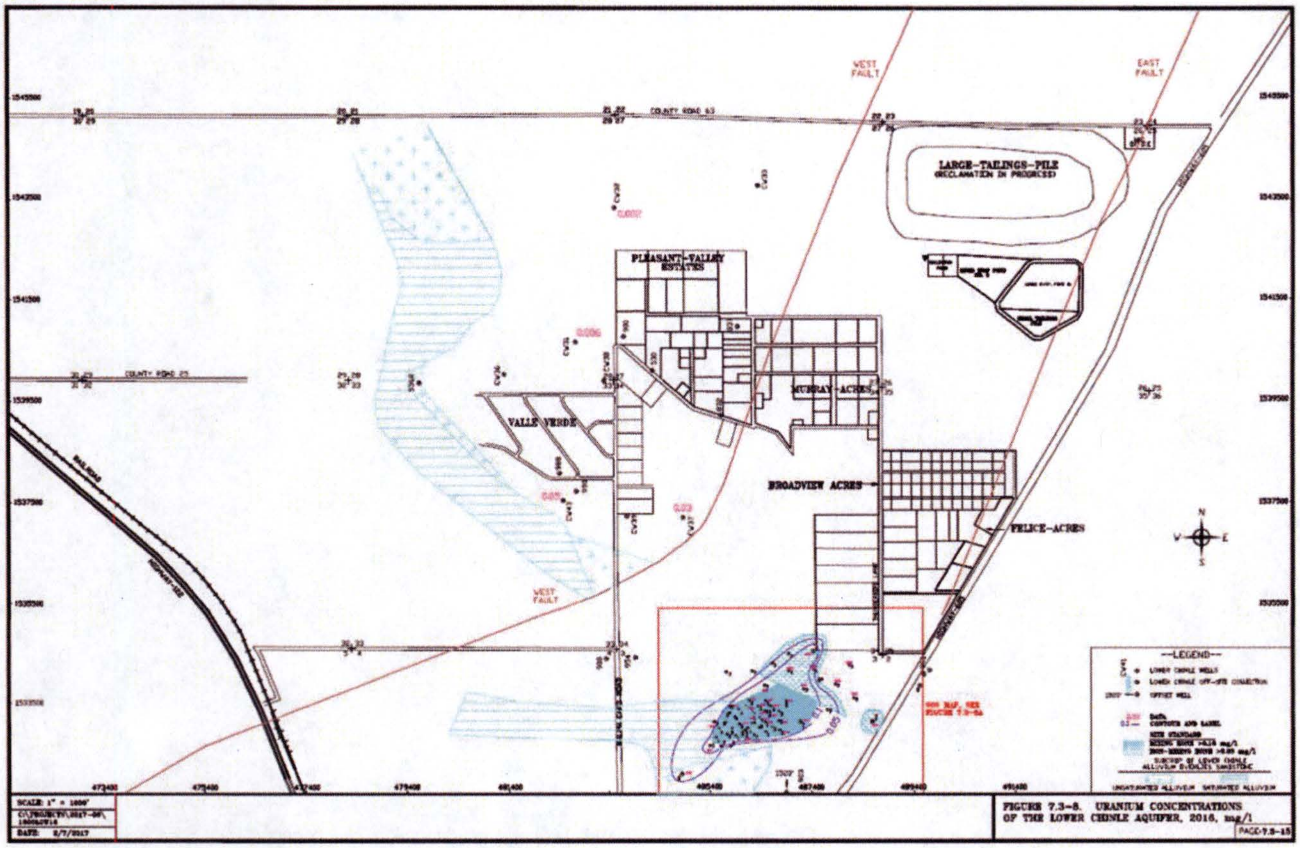


**Figure 21. Extent of Uranium Contamination in the Lower Chinle Aquifer**

*Source: Hydro-Engineering, LLC 2017*

## 2.2.5 HCM Mill Site HSCM Summary

Key elements of the Site HSCM are summarized as follows:

- The HMC Mill site is located in the southern lower portion of the SMC Basin.
- Aquifers of Quaternary, Triassic, and Permian age are present at the site.
- Principal aquifers that include groundwater flow at the site include the alluvium; upper, middle, and lower transmissive units of the Chinle Formation; and SAG aquifer.
- Local groundwater flow in the alluvium generally flows parallel to downgradient surface flows in SMC, Rio Lobo, and Rio San Jose, but bifurcates around a bedrock high located south of the LTP.
- Groundwater flow in the Chinle Formation aquifer units and underlying SAG aquifer is generally to the east-southeast, except where influenced by faulting, subcrop locations, or ongoing restoration operations.
- Site remedial activities have included groundwater extraction and injection in both the alluvial and Chinle sandstones, affecting local groundwater flow conditions.
- The presence of the East and West fault zones has restricted and redirected local groundwater flow in the Chinle aquifers, including in the vicinity of the Large Tailings Pile.
- Local groundwater flow conditions have been well characterized through data collected from hundreds of monitoring wells.

These elements of the HSCM will be translated into the site-scale flow model as described in Section 3.

# Section 3: Site-Scale (GRP) Numerical Model

This section discusses development of the Site-Scale Model, hereafter referred to as the GRP Model. The GRP Model will consist of a groundwater flow model to simulate system responses to changes in background hydrologic conditions and site remediation pumping/injection activities, and a solute transport model to simulate changes in constituent concentrations in response to ongoing remediation activities. The GRP Model will be used in the near-term to support development of the Groundwater Corrective Action Plan (CAP) and will ultimately become part of a larger-scale single model of the entire SMC Basin. The GRP Model will be developed in accordance with applicable regulatory guidance related to application of groundwater modeling at NRC and EPA CERCLA sites, including *A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites*, (NUREG/CR-6805 Neuman and Wierenga, 2003) and Guidance for Quality Assurance Project Plans for Modeling (EPA QA/G-5M, 2002). The groundwater flow and transport models will also be developed according to applicable ASTM standards.

## 3.1 Existing Site Groundwater Flow and Transport Model

A groundwater flow and constituent transport model was previously developed for use in ongoing remedial assessments and to support system management decisions for the GRP. The model was first developed in the 1990's by Hydro-Engineering and has been periodically updated for use in annual assessments of hydraulic containment system performance. The model is described in detail in Appendix G of the DRAFT Remedial Investigation Report, HDR, 2016. The model was developed using the USGS's groundwater flow code MODFLOW-96 (Harbaugh and McDonald, 1996) coupled with the solute transport code MT3DMS (Zhang and Wang, 1999). The MODFLOW/MT3DMS codes are commonly used flow and transport codes, applied by a wide variety of researchers, government agencies, and consultants to sites around the world.

The existing MODFLOW model simulates groundwater flow in 8 distinct model layers; five aquifer layers to representing the alluvial, Upper Chinle, Middle Chinle, Lower Chinle, and SAG aquifers; and three shale layers representing aquitards separating the alluvial and Upper Chinle, Upper and Middle Chinle, and Middle Chinle and Lower Chinle aquifers. The shale aquitard layers are only active in areas where there is hydraulic communication between the affected aquifers and all underlying aquifers (i.e. the aquitards are not actively simulated where the shale is simply separating flow between units, but are active only in subcrop areas where flow is moving between underlying model layers.

Flow in the alluvial aquifer (model layer 1) is simulated as unconfined. All other aquifers (and model layers) are simulated assuming confined flow conditions. Confined flow layers in MODFLOW are simulated using only transmissivity and storativity estimates and the actual geologic surfaces (i.e. stratigraphic top and bottom elevations) are not included as part of the model. Groundwater flow is simulated to occur through zones with estimated transmissivities in response to a hydraulic gradient, and is therefore not referenced to actual stratigraphic elevations. As part of this model construct, model cells cannot dewater and become unconfined, or dry out if completely dewatered, and hydraulic head is always assumed to be above the top of the stratigraphic unit.

The flow model includes simulation of surface recharge, groundwater injection and extraction via wells, and groundwater boundary inflows and outflow using general and constant head boundary conditions. The flow model version reported in the RI report (HDR, 2016) was calibrated by simulating groundwater flow between 2000 and 2004, using groundwater levels measured in 2000 as an initial condition and checking how well the model simulates water levels observed in 2004. Calibration was checked based on visual inspection of the simulated water table contours versus water table contours developed from data. No statistical comparison of water level residuals (i.e. the difference between observed and simulated water level) was provided

(HDR, 2016, Appendix G). The model was deemed reasonably calibrated to observed groundwater flow conditions and is updated annually as part of management of the hydraulic containment system. Hydro-Engineering (personal communication) notes that flow and transport model calibrations are validated on an annual basis by comparing observed versus simulated water levels to ensure the model retains calibration and continues to reasonably simulate groundwater levels.

The existing MT3DMS transport model uses the grid structure, boundary conditions, and simulated flow conditions from the MODFLOW flow model to simulate constituent transport. Constituent concentrations are input into the model as initial concentrations, concentrations in injected water, and concentrations in seepage from the LTP. A separate unsaturated (vadose) zone model was used to estimate long-term LTP seepage flow rates and chemical loading (see Section 3.6.1; HDR, 2016, Appendix G). Transport of constituents within the groundwater flow system is simulated assuming advective /dispersive transport using a finite difference solution. The model was used to simulate transport of uranium, and molybdenum. Simulations have focused primarily on uranium transport as the key indicator of local impacts and restoration process. These constituents are subject to adsorption onto aquifer materials such that they migrate somewhat slower than the surrounding groundwater (retardation). The rate of adsorption is controlled by the distribution parameter (Kd) assigned for each constituent, which can also vary spatially within the model.

The existing transport model calibration was also based on simulation of system changes between 2000 and 2004, focused on uranium transport over this time period. Simulated uranium concentrations were compared to observed concentrations in a number of key wells, and the simulated uranium plume concentration contours were visually compared to contours developed from data for 2004. The model was deemed reasonably calibrated to observed uranium transport conditions, and is updated annually as part of management of the hydraulic containment system.

## 3.2 Statement of Need

While the existing groundwater flow and constituent transport model is a reasonable representation of the system and has generally simulated long-term changes in groundwater and constituent conditions in response to remedial activities, it does not conform to the current "state-of-the-art" in modeling. The following issues have been identified with the existing model:

- The flow model was developed in MODFLOW96, which is no longer supported by the USGS and is officially listed as a legacy code that is superseded by MODFLOW-2005 and its variants (https://water.usgs.gov/ogw/modflow/superseded.html).
- The model does not include an explicit representation of site stratigraphy, but rather simulates confined flow conditions through simple transmissivity and storativity zones.
- The eastern model boundary is set close to the GRP site, potentially causing unwanted artificial influence on hydraulic heads for site wells.
- Flow model simulations have been performed using the Strongly Implicit Procedure (SIP) solver. State-of-the-art solvers, including preconditioned conjugate gradient solvers, geometric multigrid solvers, and Newton-Raphson nonlinear solvers are included with updated versions of MODFLOW and provide for more efficient solutions with improved mass balances.
- Flow model calibration was not based on standard statistical approaches to assess if simulated residuals are minimized and meet generally acceptable criteria related to model calibration.
- The transport model is based on a simplified representation of uranium transport based on the advective/dispersive equation with simple retardation. The model does not include a means for assessing the influence of aquifer minerology and redox conditions on transport.

- The transport model uses a finite difference solution technique which can result in significant numerical dispersion. Other more robust solution methods are available within MT3DMS to minimize numerical dispersion and improve solution mass balances.
- The existing flow and transport model is not compatible with modern pre- and post-processing software that allows for efficient development of model updates and enhanced visualization of model setup, parameter inputs, and simulation results.

Based on these considerations, a new flow and transport model will be created using state-of-the-art techniques and codes.

## 3.3 Model Code Selection

MODFLOW One-Water Hydrologic Model (OWHM) was chosen as the code for developing the GRP Model (Hanson, et. al, 2014). MODFLOW-OWHM is currently a core version of MODFLOW fully supported by the USGS, and incorporates several MODFLOW capabilities from various independent versions of MODFLOW such as detailed surface water balances and water delivery routing (through the Farm process), enhanced solution procedures including PCG, GMG, and Newton-Raphson solvers, the subsidence and seawater-intrusion packages, and local-grid refinement (LGR) capability. For the GRP Model specifically, the choice of solvers and the LGR capability are considered critical to successful model development.

The GRP transport model will be developed using MT3D-USGS (Bedekar, et. al., 2016). MT3D-USGS is a USGS updated release of the groundwater solute transport code MT3DMS. MT3D-USGS includes new transport modeling capabilities to accommodate flow terms calculated by MODFLOW packages that were previously unsupported by MT3DMS and provides greater flexibility in the simulation of solute transport and reactive solute transport. The MT3D-USGS model capabilities and features include:

- Unsaturated-zone transport;
- Transport within streams and lakes, including solute exchange with connected groundwater;
- Capability to route solute through dry cells that may occur in the Newton-Raphson formulation of MODFLOW (that is, MODFLOW-NWT);
- New chemical reaction package options that include the ability to simulate interspecies reactions and parent-daughter chain reactions;
- new pump-and-treat recirculation package that enables the simulation of dynamic recirculation with or without treatment for combinations of wells that are represented in the flow model, mimicking the above-ground treatment of extracted water;
- Reformulation of the treatment of transient mass storage that improves conservation of mass and yields solutions for better agreement with analytical benchmarks;
- Separate specification of the partitioning coefficient (Kd) within mobile and immobile domains;
- Capability to assign prescribed concentrations to the top-most active layer;
- Change in mass storage owing to the change in water volume now appears as its own budget item in the global mass balance summary;
- Ability to ignore cross-dispersion terms; and
- Ability to specify an absolute minimum thickness rather than the default percent minimum thickness in dry-cell circumstances.

While not all of these capabilities are applicable to the GRP Model, the enhanced transport capabilities will be evaluated and used where appropriate to provide for more robust transport simulation and calibration.

HMC has recently initiated a geochemical characterization program designed to better define the tailings source term and alluvial aquifer attenuation characteristics. The program will collect data on tailings minerology, redox conditions, and pore-water concentrations to develop a better understanding of solid-phase controls on COC concentrations. The site-specific geochemical program results will be incorporated into the GRP transport model.

## 3.4 Three-Dimensional Geologic Model

The stratigraphy and geologic structures that define the GRP and conditions local and regional to the Site are complex. A 3-D model of geologic stratigraphy and faulting will be developed to better understand and visualize the complex geologic features that influence groundwater flow at the HMC Mill Site. The model will be developed using Leapfrog™, a geologic modeling software that uses drill logs, point data, and surface data to generate three-dimensional interpolated views of a geologic system.

A previous geologic model was developed for the Site using Earth Visualization Software (EVS). The EVS model only covers a limited area of the site, and does not include the entire previous groundwater model extent (Figure 22). Leapfrog software has been designed to seamlessly integrate with MODFLOW models through efficient data import and export schemes that allow for efficient transfer of geologic surface and other data into MODFLOW format that are not available with EVS. The existing EVS geologic model will be transferred into Leapfrog format as a base for the updated geologic model. The geologic model will then be extended across the entire flow model domain using existing site data along with regional mapping and other geologic interpretations. Once finalized, stratigraphic surfaces representing the top and bottom elevations of the intervening shale and sandstone units, along with the location of the East and West fault structures, will be exported from Leapfrog into MODFLOW model format for use in the GRP Model.

## 3.5 Model Domain

Given that the previous groundwater flow model provides a reasonable representation of system conditions, the updated GRP model will be based on the previous model construct to the maximum extent practical. The GRP Model will use the same lateral model domain as the existing model, as shown in Figure 22. The model extent covers approximately 42 square miles surrounding the HMC Mill site. Figure 23 shows the existing model grid, which will also be used. The grid has finer discretization around the LTP, with the smallest cell size at 50 by 50 feet. Note that the model extent and grid structure may be modified during GRP Model development if warranted.

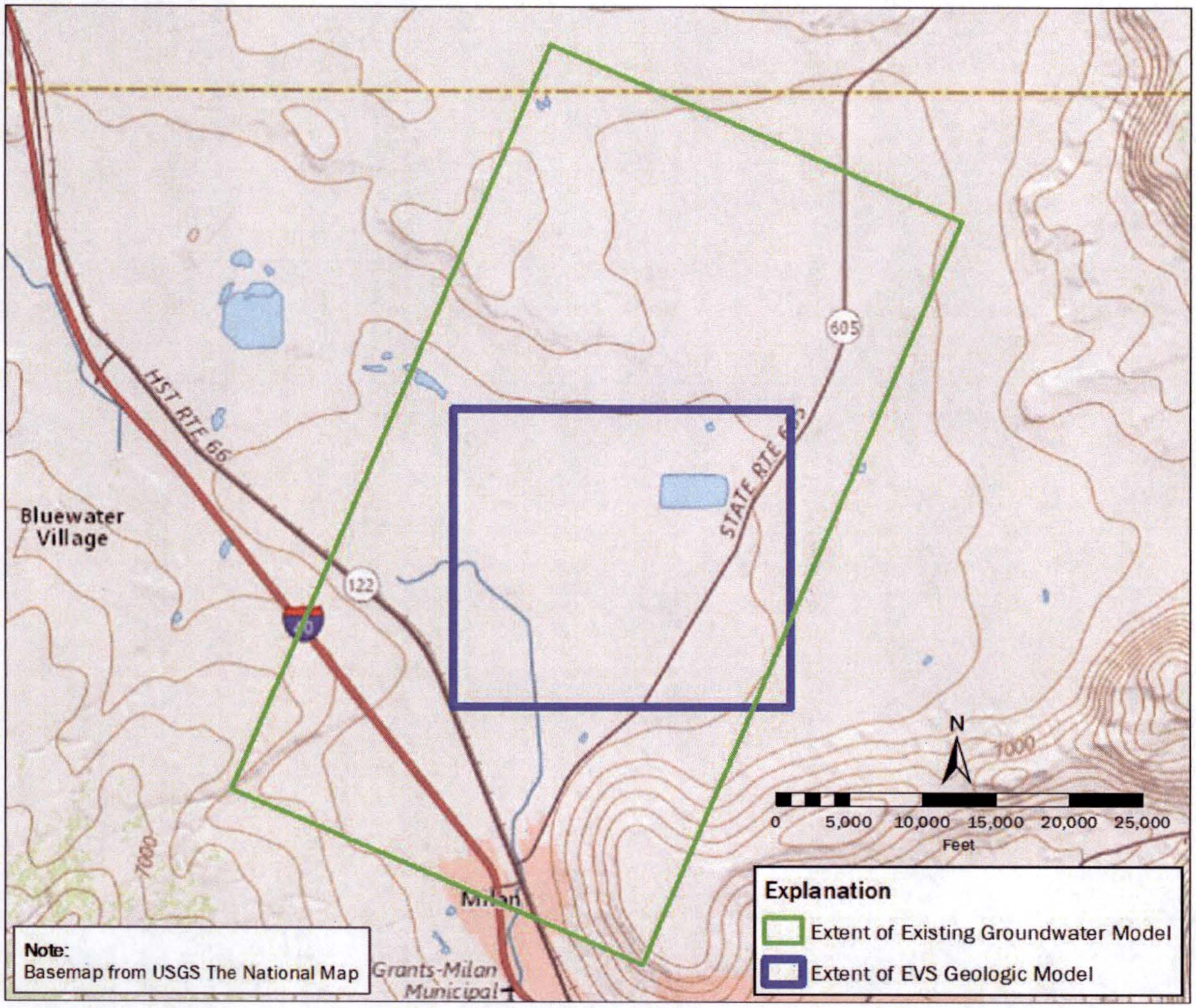


Figure 22. GRP Model Domain

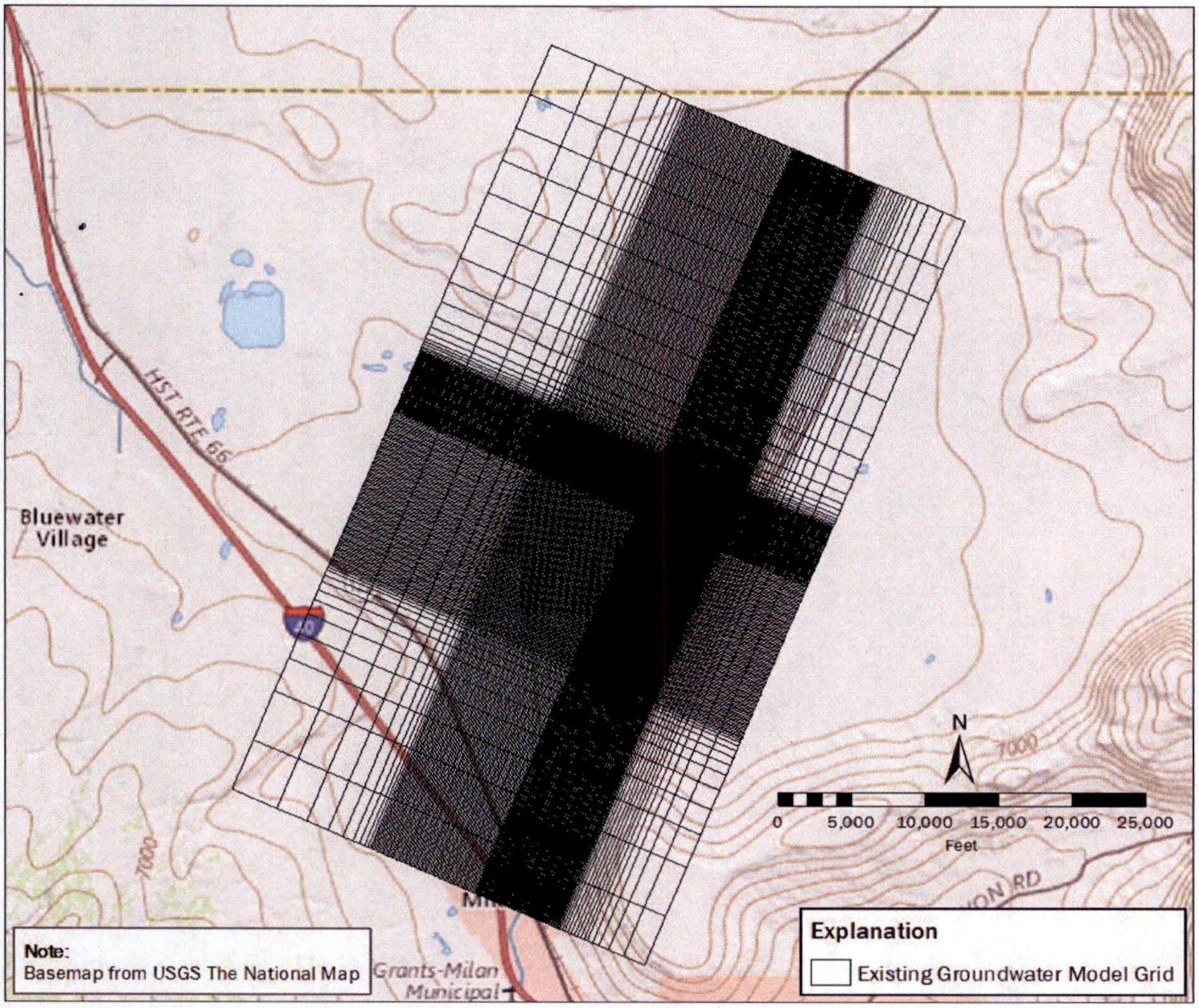


**Figure 23. GRP Model Grid**

The GRP Model will be developed with nine vertical layers (Figure 24), as follows:

- Layer 1 – Alluvium
- Layer 2 – Shale unit separating surface alluvium from the Upper Chinle aquifer
- Layer 3 – Upper Chinle aquifer
- Layer 4 – Shale unit separating the Upper and Middle Chinle aquifers
- Layer 5 – Middle Chinle aquifer
- Layer 6 – Shale unit separating the Middle and Lower Chinle aquifers
- Layer 7 – Lower Chinle aquifer
- Layer 8 – Shale unit separating the Lower Chinle aquifer from the SAG aquifer
- Layer 9 – SAG aquifer


**Figure 24. GRP Model Layering Stratigraphic Column**

The GRP Model construct will use geologic surfaces developed from the Leapfrog model to define the thickness and extent of each model layer. The model layers will be active within the domain only where the unit spatially exists. For example, the Upper Chinle aquifer exists only in the east-northeast portion of the model domain (Figure 25).

In the previous model, layers representing the Middle and Lower Chinle units were truncated near the site and were not simulated over the entire extent of the model domain, even though the aquifer exists in those areas. Figure 26 presents the representation of the Middle Chinle aquifer (model layer 5) from the previous model, indicating that the full extent of the aquifer within the model domain was not simulated. As shown on the Figure, the GRP Model will increase the extent of this layer to the model boundary, based on the interpretation of the Middle Chinle developed in the Leapfrog geologic model.

The GRP Model is designed to simulate south to southwest flow in the alluvium originating from flow upgradient and recharge into the aquifer. Flow interactions between the alluvium and underlying Chinle aquifers occur primarily in areas where the Chinle sandstones sub-crop beneath the alluvium. These areas will be designated in the model via variations in vertical hydraulic conductivity (i.e. vertical conductance). Groundwater flow in the Chinle units is generally from alluvial recharge through the sub-crop areas down-dip toward the east-northeast. Groundwater flow in SAG is generally isolated from the overlying aquifers and is from west to east.

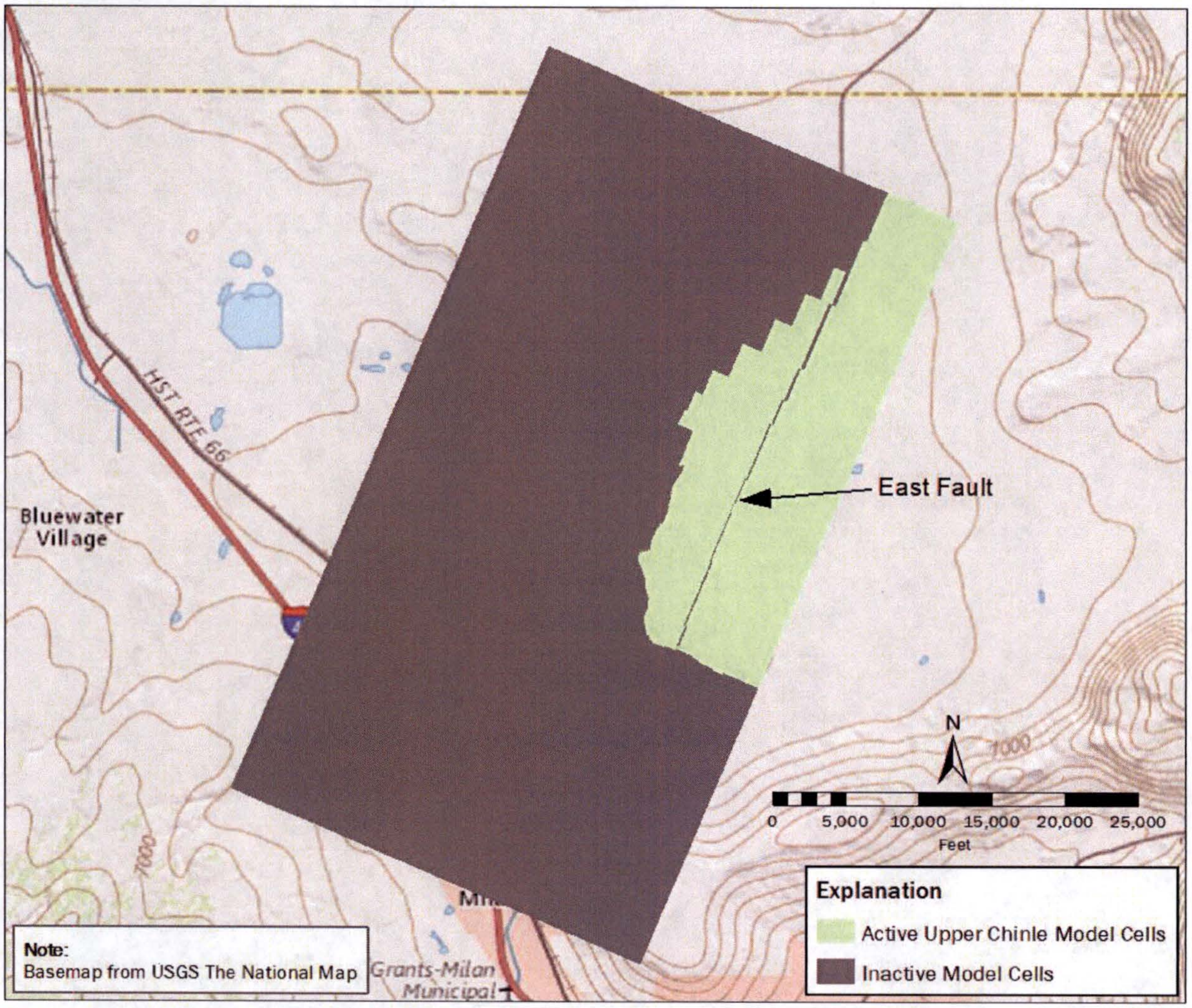


**Figure 25. Simulated Extent of the Upper Chinle Aquifer from old model**

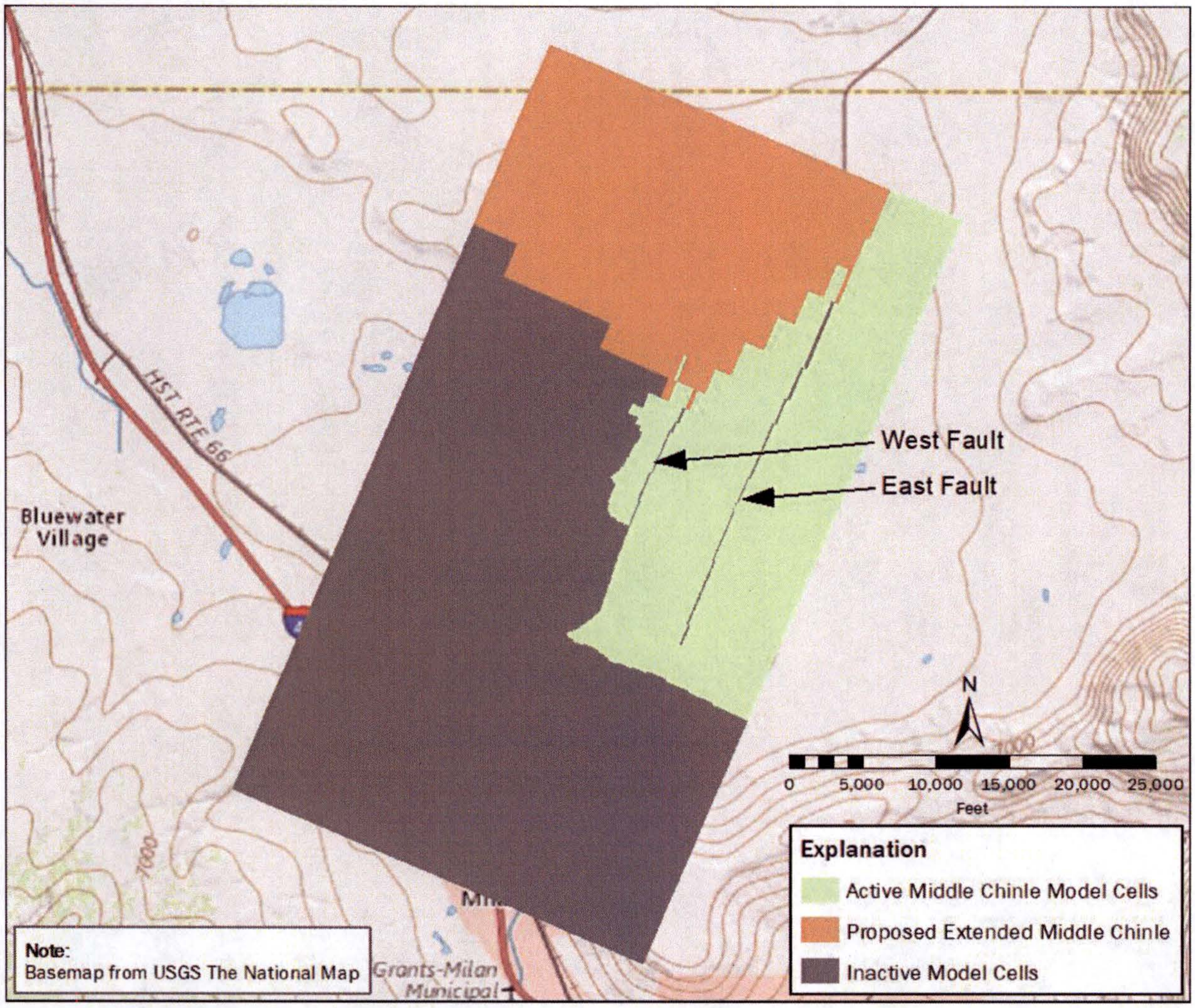


**Figure 26. Proposed Simulated Extents of the Middle Chinle Aquifer for new model**

## 3.6 Flow Model Boundary Conditions

Model boundary conditions provide a means to add flow into the groundwater system (as recharge, well injection, or upgradient inflow) and to allow for flow out of the system (as well pumping, flow into tailings toe drains, or as outflow downgradient). Groundwater flow can also be affected by no-flow boundaries and fault structures that restrict flow. Boundary conditions developed for the previous model will be used for preliminary model development, and modified as warranted during model testing and calibration.

### 3.6.1 Groundwater Recharge

Background recharge from seasonal precipitation is applied to the alluvial aquifer (Layer 1) through the MODFLOW Recharge (RCH) package. The previous model assumed a long-term average recharge of approximately 0.5 inches per year. This assumption will be reviewed and updated as part of GRP Model development.

Seepage from the LTP represents an important source of both recharge and chemical mass loading to the local groundwater system. A separate seepage model (the reformulated mixing model) has been developed to assess long-term changes in both seepage flow rates and constituent mass loading (HDR, 2016, Appendix G). Assessments of past LTP seepage rates, along with predictions of future seepage rates, have been developed based on vadose modeling using the VADOSE/W code. Development, calibration, and application of the VADOSE/W seepage model is described in HDR, 2016, Appendix G. Seepage estimates developed from that model will be used in the GRP Model to simulate flow from the LTP into the local groundwater system. Seepage from the LTP is currently simulated through a series of 27 injection "points" using the MODFLOW Well (WEL) package. Each point is simulated with the same seepage rate, updated annually. This approach will be evaluated as part of GRP Model calibration and updated if warranted.

### 3.6.2 Well Pumping and Injection

Ongoing remediation of groundwater includes both groundwater injection and extraction to create and maintain a hydraulic barrier to control potential groundwater migration away from the LTP footprint. The general groundwater restoration sequence utilizes injection of high-quality fresh water and treated water from the reverse osmosis (RO) process around the impacted area with simultaneous collection to contain impacted water. The injection of unimpacted water serves the primary purpose of enhancing and expanding a hydraulic barrier to further limit uranium/COC migration and directing impacted groundwater to collection wells.

Volumes, rates, and locations of injection and extraction have varied over time to optimize system performance and maintenance of the hydraulic barrier, and are re-assessed and modified on roughly an annual basis. Past pumping and injection rates and locations have been organized into a database, and will be simulated in the GRP Model using the MODFLOW Well (WEL) package.

### 3.6.3 Surface Water

As discussed previously, surface water streams are ephemeral and consist of the San Mateo Creek, Lobo Canyon drainage, and Rio San Jose. Surface flows in these creeks and drainages are virtually non-existent and may only occur for short periods of time in response to extreme snowmelt and/or summer thunderstorm events. In the upper parts of SMC and Lobo Canyon, on the eastern side of Mount Taylor, perennial flow occurs at San Mateo Springs, an unnamed tributary of SMC, and an unnamed tributary of the Lobo Canyon drainage (see Figure 27). Further up-valley from the Routes 605/509 intersection leading to the village of San Mateo, the San Mateo Creek may be more perennial. If historical records indicate this is the case, then surface water flows will also be simulated for this stream reach. Surface water flows will not be simulated in the site-specific model for the GRP but will be for the reaches described above in the regional model.

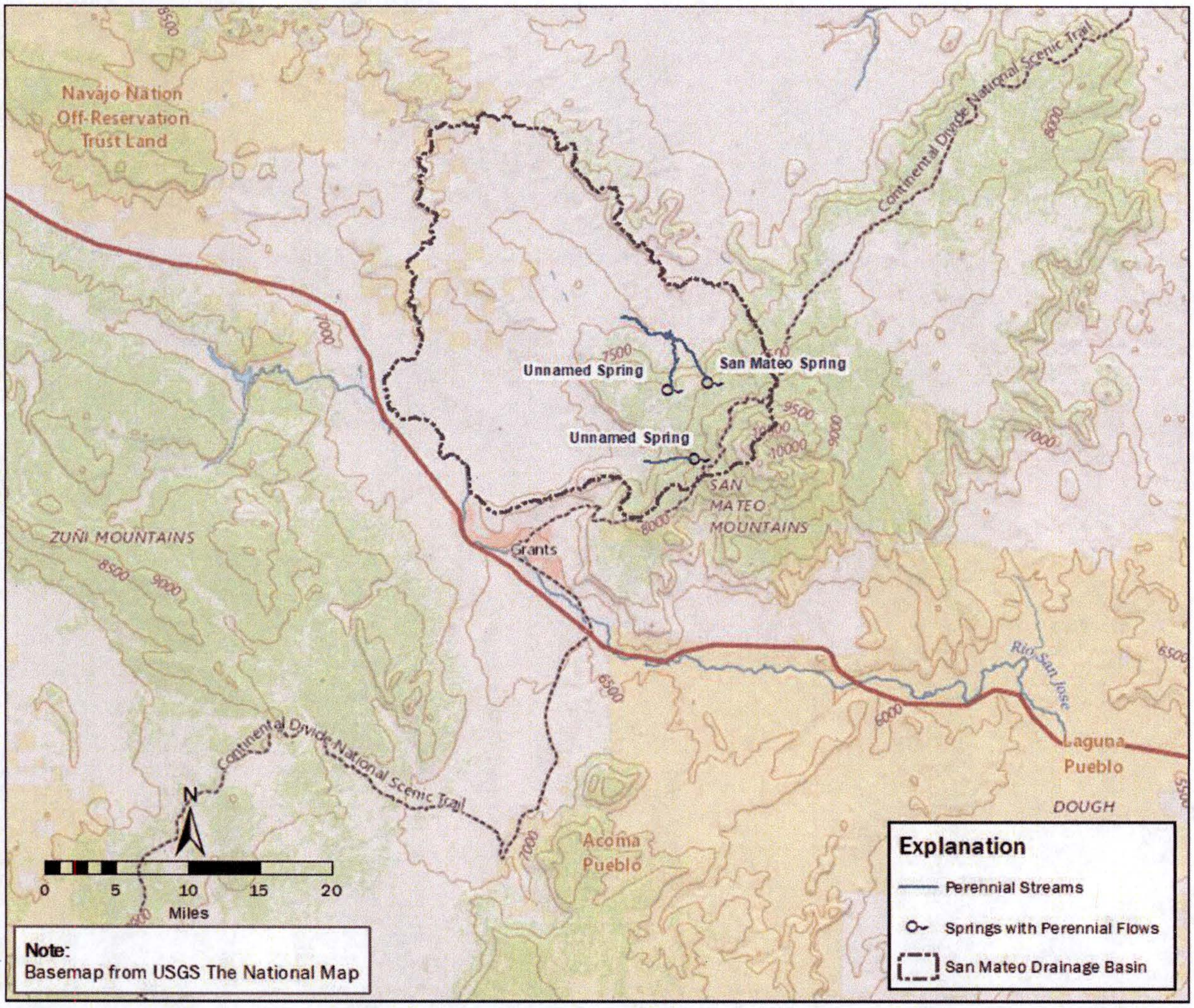


**Figure 27. SMC Basin Surface Water Features**

### 3.6.4 Boundary Conditions – Groundwater Discharge

Groundwater flow into the model domain, along with outflow of groundwater out of the domain will be simulated using head-dependent boundary conditions. The existing model uses the MODFLOW General Head Boundary (GHB) condition to simulate flows into and out of Layer 1 (alluvium), and constant head boundaries for all other aquifers. GHBs allow for the simulated groundwater level at the boundary to vary in reference to a prescribed level set at some distance outside the model domain. Constant head boundaries fix the groundwater level at the boundary, and the model simulates a groundwater flow rate into or out of the model cell sufficient to keep the fixed water level.

Head referenced boundaries (GHBs and constant heads) are important as they prescribe the general limits of groundwater elevations, allowing the model to accurately simulate elevations observed in the field. The GRP Model will be updated to use GHBs rather than constant heads, to allow for variation in simulated water levels in each of the layers at the model boundaries.

### 3.6.5 Fault Structures

The East and West faults at the HMC Mill site (as shown on Figure 12) have been shown to significantly restrict lateral groundwater flow across the faults in the Chinle aquifers. The existing model uses no-flow cells to simulate the effect of the faults. Use of no-flow cells to represent faults does not allow for any flow (even extremely low flows) across the faults, which in turn can result in model solution stability issues. The East and West faults in the GRP Model will be simulated using the MODFLOW Horizontal Flow Barrier (HFB) package. The HFB package is specifically designed to simulate thin, vertical low-permeability geologic features (Hsieh and Freckleton, 1993) by adding the feature between model cells, rather than using the entire cell thickness. The hydraulic conductivity of the feature can be varied to achieve a reasonable non-zero flow rate across the faults. Locations of the East and West faults in the GRP Model will be developed from the Leapfrog geologic model. Fault material properties (assumed width and hydraulic conductivity) will be developed and tested as part of model calibration.

## 3.7 Aquifer Physical Properties

Measurement of aquifer properties for the Alluvial and Chinle aquifers has occurred over many years as wells have been installed and tested. The existing model was developed based on site data, with limited modifications during model calibration. The GRP Model will use all existing parameter estimates and zonations from the existing model as an initial condition. Ranges of hydraulic conductivity, transmissivity, specific yield, and storage estimates for the existing model are summarized on Table 3-1. Modifications to parameter estimates and zonation may be developed during calibration of the GRP Model.

**Table 3-1. Summary of Aquifer Physical Properties for the GRP Model**

| Aquifer Unit | Hydraulic Conductivity (ft/day) | Transmissivity (ft^2/day) | Specific Yield | Storativity |
|---|---|---|---|---|
| Alluvium | 10 to 800, typically 30 to 60 | - | 0.12 to 0.20 | - |
| Upper Chinle | - | 4 to 1,337, typically 40 to 100 | - | 1.00E-05 |
| Middle Chinle | - | 7 to 2,674, typically 30 to 300 | - | 1.00E-05 |
| Lower Chinle | - | 1 | - | 1.00E-05 |
| San Andres/Glorietta | - | 60,000 | - | 1.00E-05 |
| | | | | |
| Source: HDR, 2016 | | | | |

## 3.8 Flow Model Calibration

As noted, the existing groundwater flow model was calibrated to 2000 to 2004 conditions based on visual inspection of simulated versus mapped groundwater level contours. As part of model calibration, available water level, pumping/injection, and constituent concentration data will be reviewed and an updated calibration period will be developed. This may include both steady state calibration to a relatively stable past condition and a transient calibration to a longer-time period than the previous model calibration.

The GRP Model will be calibrated using standard flow model statistical methods. Calibration of the groundwater flow model is the process of adjusting hydraulic parameters, boundary conditions and initial conditions within reasonable ranges to obtain a match between observed and simulated potentials, flow rates, or other calibration targets. The standard guide for calibration a groundwater flow model (ASTM D 5981 - 96) will be referenced for the calibration of the model.

The model calibration will be accomplished primarily through trial-and-error adjustment of the model's input data to match field observations. Automatic inverse techniques such as PEST (Doherty, 2004) may be considered if warranted. The calibration process will be evaluated through analysis of residuals. A residual is the difference between the observed and simulated groundwater level. Calibration may be viewed as a regression analysis designed to bring the mean of the residuals close to zero and to minimize the standard deviation of the residuals.

Standard calibration statistics based on the residual are used as a quantitative measure of the ability of the model to match calibration targets. Calibration statistics that are used to quantify the average error may include:

- Mean Absolute Error, the average of the absolute value of the residuals;
- Root Mean Squared Error, the square root of the average of the square of the residuals (this statistic adds weight to larger residuals);
- Residual Mean, the average of the residuals;
- Scaled Absolute Mean, the mean absolute error divided by the total range in observed groundwater elevation values;
- Scaled Root Mean Square Error, the standard deviation of the residuals divided by the total range in observed groundwater elevation values.

It is important to note that an industry defined statistical range that identifies a well calibrated model does not exist, since modeling by necessity requires subjectivity and the acceptability of a calibration is directly dependent on the modeling objective (Anderson et al. 2015). The GRP Model will be calibrated with a focus on minimizing the residual statistics defined above, based on professional judgement and to a point where further minimization cannot be reasonably achieved.

## 3.9 Transport Model

The existing constituent transport model will be updated for use in MT3D-USGS. The GRP Model will simulate advective-dispersive transport of COCs (primarily uranium) with long-term mass loading from the LTP source. As noted, a separate seepage model (the reformulated mixing model) has been developed to assess long-term changes in both seepage flow rates and constituent mass loading (HDR, 2016, Appendix G). The existing model is based on dispersivity estimates and retardation coefficients developed from field testing of constituent migration from a known source (injected water). Differing rates of migration were observed between conservative ions and those subject to attenuation, including uranium, molybdenum, and selenium. Estimates from the field test were used to visually calibrate the transport model and for future simulations.

The transport portion of the GRP Model will initially be based on the existing transport model, using existing parameterization (porosity, dispersivity, retardation coefficients) and source loading assumptions. As previously noted, HMC has recently initiated a geochemical characterization program designed to better define the tailings source term and alluvial aquifer attenuation characteristics. The program will collect data on tailings minerology, redox conditions, and pore-water concentrations to develop a better understanding of solid-phase controls on COC concentrations. While the GRP Model will initially be based on previous assessments, longer-term data from the geochemical characterization program will be used to eventually update transport model assumptions as warranted.

The existing transport model was calibrated to 2000 to 2004 conditions based on visual inspection of simulated versus mapped COC concentration contours and the comparison of observed versus simulated concentration declines in key wells. As part of model calibration, available constituent concentration data will be reviewed and an updated calibration period will be developed. This will likely include a longer-time period for GRP Model transport calibration.

In general, statistical analyses of the type used for flow model calibration are not used to assess transport model calibration, as the simulated extents and concentrations of COCs are highly dependent upon the assumed number, locations, extents, timing, volumes and mass loading of uncertain releases to groundwater. Transport calibration is rather focused on evaluations of how well the model simulates known conditions as they relate to source mass loading assumptions (i.e. matching historical constituent migration based on assumed source conditions). For the GRP Model, transport calibration will be judged using a similar approach as the existing model; visual inspection of plume contours and comparison of simulated concentrations over time at key well locations. It is anticipated that GRP Model transport calibration will include additional timeframes for plume comparison, and additional well locations for concentrations comparison over what was used before.

## 3.10 Predictive Simulations

Once reasonable calibration is achieved, the GRP Model will be used to simulate the fate and transport of COCs under current and potential future GRP groundwater restoration activities. The predictive model will focus on assessing both near-term cleanup timeframes (for Site closure) and long-term post-closure conditions as part of Corrective Action planning. In addition, scenarios may be developed to assess restoration system performance and clean-up time frames under various pumping/injection regimes to enhance cleanup times and/or reduce long-term constituent concentrations. The primary output of predictive simulations will be simulated concentrations at key wells within the GRP. Ultimately, the GRP Model will be combined with the SMC Basin Model into a single tool to assess basin-wide system responses to ongoing remedial activities and long-term COC fate and transport

## 3.11 Uncertainty Assessment

Simulation of potential future groundwater flow and COC fate and transport is by its nature uncertain. Extensive data collection over many years from hundreds of wells installed at the site has reduced uncertainties in knowledge of geologic characteristics, groundwater system behavior, and COC transport at the Site. Site restoration activities have resulted in verified and observable reductions in COC concentrations in groundwater. Future system responses to pumping and injection will be similar to those currently observed at the Site. Ongoing uncertainty remains in the assumption that the majority of the uranium in the LTP tailings solids is present as soluble uranium in pore water, such that the predicted long-term concentrations in LTP seepage will remain stable. Uncertainty in source mass loading from the LTP will be reduced through the geochemical characterization program.

Model uncertainty will be assessed through sensitivity analysis. Sensitivity analyses consisting of systematic adjustment of calibration flow model parameters will be performed to evaluate how flow and transport parameter uncertainty influence model predictions of COC migration, maintenance of hydraulic containment, and COC concentration declines. Uncertainty in LTP source mass loading will be assessed by simulating future conditions under a variety of assumed mass loading scenarios. The sensitivity analyses will be used to provide a bound for both short-term closure assumptions and long-term COC concentration predictions.

# Section 4: Regional (SMC Basin) Numerical Model

The regional-scale model, referred to as the SMC Basin Model, will be developed concurrently with the GRP Model and will simulate flow and constituent transport at the Basin scale. The SMC Basin Model will be developed using the same software (MODFLOW-OWHM and MT3D-USGS) as the GRP Model.

## 4.1 Statement of Need

As previously noted, the SMC Basin is within the Grants Mineral Belt, which produced more uranium than any other district in the world during the period 1951–80 (HDR, 2016). There are more than 85 legacy mining and mill sites in the SMC Basin and mining and remediation activities have had a significant impact on local and regional groundwater flow conditions and water quality. Significant remedial activities have occurred in four uranium mill sites in the SMC Basin (Figure 2). These include the HMC Mill site, the Bluewater Mill site, the Rio Algom/Quivira Mill site (also referred to as the Ambrosia Lake Mill site) and the Phillips Mill site (Figures 1 and 2). Significant groundwater data have been collected at these sites associated with past and ongoing remedial activities.

The EPA and the New Mexico Environment Department (NMED) have recently performed assessments on the overall health and environmental impacts of uranium mining and milling in the Grants Mining District, including legacy contamination of structures, surface and groundwater resources, and sediment within the SMC Basin (NMED, 2012, Weston, 2016). HMC has been a cooperating partner in these assessments.

HMC has developed a regional-scale hydrogeologic conceptual model for the SMC Basin (BC, 2018) to support development of a regional-scale groundwater flow and chemical transport model. The goal of the regional model is to have a tool to assess past, present, and future impacts from historic mining and milling activities, potential hydraulic interactions between historic sites and the GRP, and to assess basin-scale responses to ongoing remedial activities. There will ultimately be a single model simulating flow and transport within the SMC Basin and the GRP. As an interim step toward the single model, a regional-scale (SMC Basin) model will be developed, as described in this Section.

## 4.2 Leapfrog Geologic Model

The SMC Basin Model is designed to simulate general groundwater flow and constituent transport at a regional scale. As with the GRP Model, the first step in model development will be to develop a 3-D geologic model of the SMC Basin using Leapfrog. While geologic data are available for the mill sites undergoing remediation, basin-scale geologic data are limited. The geologic model for the SMC Basin will be developed from available data and assumed conditions developed from regional geologic reports, maps, and cross-sections. The model will include primary regional fault structures and known and interpreted stratigraphic offsets across the faults. Stratigraphic surfaces from the Leapfrog model will be exported for use in MODFLOW for development of the SMC Basin Model.

## 4.3 Model Domain

The SMC Basin Model will encompass the principal regional aquifers present in the basin and the regional SAG aquifer. A preliminary model extent is shown on Figure 28, which is intended to include both north to northeast flow in the Cretaceous, Jurassic, and Triassic aquifer and east to southeast flow in the underlying SAG (Permian) aquifer. The SMC Basin model will be developed using a uniform grid spacing of 1,500 by 1,500 feet, subject to change based on model testing, with finer grid discretization in the area of the GRP and potentially Ambrosia Lake and Bluewater Mill. Finer-scale discretization may be added in other areas if historical hydraulic head information allows and the need is warranted.

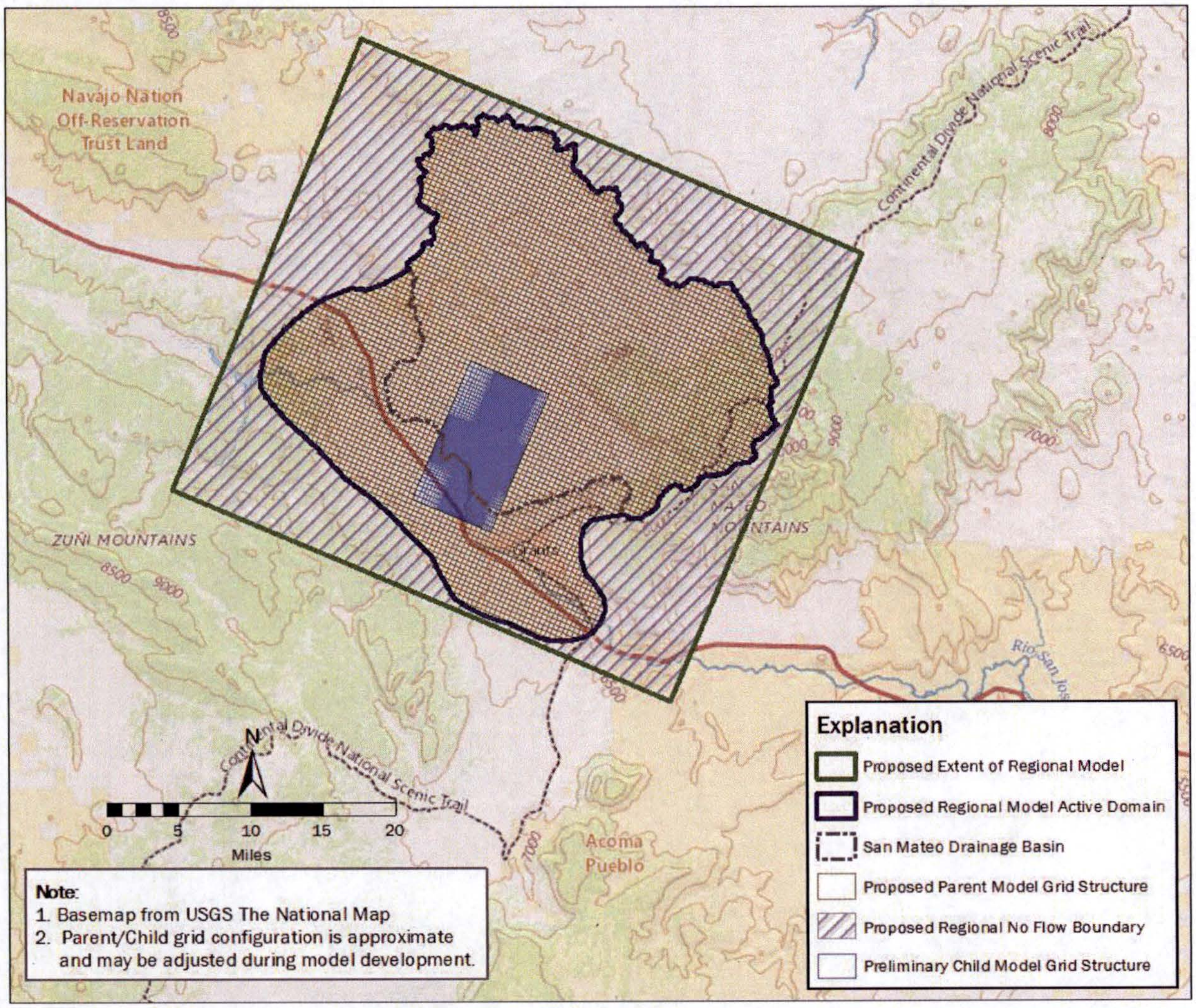


**Figure 28. Proposed SMC Basin Model Extent**

The SMC Basin Model will initially be developed with a total of 12 model layers (Figure 29), as follows:

- Layer 1 - Quaternary valley fill deposits (alluvium) – this unit will extend across multiple model layers such that alluvium can overlie the appropriate underlying sedimentary unit
- Layer 2 - Menefee Formation
- Layer 3 - Point Lookout Sandstone
- Layer 4 - Crevasse Canyon Formation
- Layer 5 - Gallup Sandstone
- Layer 6 – Mancos Shale
- Layer 7 - Dakota Sandstone
- Layer 8 - Morrison Formation
- Layer 9 - Bluff Sandstone
- Layer 10 - Entrada Sandstone
- Layer 11 – Chinle Shale
- Layer 12 – SAG aquifer


**Figure 29. Proposed SMC Basin Model Layering Stratigraphic Column**

This initial layer structure may be changed during model development. Additional separating units may be added as necessary, and additional flow layers (such as splitting the Westwater Canyon Member out from the rest of the Morrison Formation) may be warranted. The final layer structure will be determined during development of the Leapfrog geologic model.

The SMC Basin Model construct will use geologic surfaces developed from the Leapfrog model to define the thickness and extent of each model layer. The model layers will be active within the domain only where the unit spatially exists.

## 4.4 Flow Model Boundary Conditions

Flow model boundary conditions will be developed based on the Regional HSCM described in BC, 2018, including historic data and reports when available. At a regional scale, most of the aquifer units receive recharge at surface outcrop locations as mapped in the basin. Recharge will be added at the appropriate outcrop locations via the MODFLOW RCH package. Recharge to the alluvium from background precipitation will also be added as appropriate. Actual recharge rates both to the alluvium and bedrock outcrop areas will be developed based on historic climate and other available information. Rates may be modified during model calibration to improve model simulations of conceptual groundwater flow conditions.

Groundwater flow is generally down-dip toward the north-northeast, as illustrated in Figure 8. General head boundaries will be developed to provide appropriate outflow boundaries at appropriate groundwater levels for each regional unit, as indicated from historic data and reports, and/or professional judgement.

Creeks and streams will be represented using the MODFLOW SFR package. The location and elevation of streambeds will be developed based on regional mapping and available topography information from the USGS Digital Elevation Model (DEM) dataset (USGS, 2015). Local and regional USGS streamflow data will be reviewed and background flow rates and timing of seasonal and infrequent runoff into the creeks will be developed based on climate records, and recharge from these flows to the groundwater system will be evaluated during SMC Basin Model calibration.

Regional groundwater pumping from wells located in various aquifers will be simulated using the MODFLOW WEL package to the extent well locations and pumping rates can be identified. Historic groundwater pumping from uranium mining and associated discharges to surface streams is an important component of the SMC Basin model. Total estimate pumping rates identified in the HSCM (BC, 2018) will form the basis for simulating this pumping and discharge. Additional review of historic information and model testing will be used to develop locations, rates, and timing of pumping as available.

Numerous regional and local fault structures have been identified in the basin. Known structures (such as the East and West faults at the GRP and faulting characterized at the Bluewater Mill site) will be simulated using the MODFLOW HFB package. Other mapped faults will be simulated as part of sensitivity analysis to determine their potential influence on regional groundwater flow

## 4.5 Aquifer Physical Parameters

Available aquifer physical parameter data has been summarized in the Regional HSCM (BC, 2018) and in USGS, 2015. Table 4-1 summarizes this information. Various estimates of hydraulic conductivity and storage parameters will be tested during initial model development, and additional zonation may be added to certain model layers to improve general model calibration as warranted.

**Table 4-1. Summary of Aquifer Hydraulic Conductivity for the SMC Basin Model**

| Aquifer | Hydraulic Conductivity (ft/day) |
|---|---|
| Alluvium | 2- 800 |
| Menefee | 0.005 to .01 |
| Point Lookout | 0.002 - 02 |
| Crevasse Canyon | 3 - 250 (transmissivity) |
| Gallup Sandstone | 0.1 to 1.0 |
| Dakota Sandstone | 0.0004 to 1.5 |
| Morrison Formation | ~ 0.1 |
| Bluff Sandstone | 3- 50 (transmissivity) |
| Entrada Sandstone | 0.5 to 5.0 |
| Chinle Group (regional) | 10e-08 to 0.1 |
| San Andres/Glorieta | 10 to 450,000 (transmissivity) |
| | |
| Source: Langman, et al, 2012 | |

## 4.6 Model Simulation Period

A key goal for the SMC Basin model is to provide a general assessment of historic pumping and a reasonable representation of potential past flow conditions in the basin resulting from uranium operations. During model development, an appropriate period will be chosen for simulation, covering at least the period of historic uranium mining and milling operations (1951 through present). At a minimum, a steady-state representation of pre-development groundwater conditions will be developed, and transient simulations using an appropriate stress period (likely annual) will be developed using the steady-state results as an initial flow condition.

## 4.7 Flow Model Calibration

Groundwater levels for various aquifers are limited, but some data are available, as described in the HSCM (BC, 2018). In addition, groundwater levels specific to the four uranium mill sites are available as part of past and ongoing remedial activities. The goal of calibration for the SMC Basin Model is to generally simulate known and inferred groundwater flow conditions at a regional scale. As such, detailed statistical analysis of the type described in Section 3.8 will not be used to assess flow model calibration. A general assessment of groundwater flow directions, hydraulic gradients, and comparison to known water levels will be made to determine the model's suitability as a tool for simulating regional groundwater flow.

## 4.8 Transport Model

Once the SMC Basin Model is deemed to reasonably simulate historic and current regional groundwater flow conditions, a transport model will be developed to simulate the general fate and transport of COCs from four mill sites in the Basin. A focus of these simulations will be COC migration from the Ambrosia Lake area of the SMC Basin and prediction of off-site San Mateo uranium-selenium plume movement towards the GRP.

The transport model will be developed using similar assumptions and parameter estimates as the GRP Model. This includes existing parameter estimates for dispersity, porosity, and COC retardation coefficients primarily in the alluvial aquifer. Given the uncertainty of these parameters for regional-scale aquifer units, development of the transport model will include significant testing and sensitivity analyses related to parameter uncertainty.

## 4.9 Uncertainty Analysis

Given the limited geologic, hydrogeologic, and water quality data available for detailed characterization of regional conditions, the SMC Basin Model will require numerous assumptions related to model layer thicknesses, hydraulic conductivity, groundwater levels and hydraulic gradients, historic pumping and water use, historic discharges to surface water, and constituent transport conditions. As with the GRP Model, model uncertainty will be assessed through sensitivity analysis. Sensitivity analyses consisting of systematic adjustment of calibration flow model parameters will be performed to evaluate how flow and transport parameter uncertainty influence model predictions of regional groundwater flow conditions, changes in conditions from historic mining activity, and long-term, regional-scale constituent migration. Results from the sensitivity analysis will be used to provide a range of potential groundwater flow conditions and constituent migration patterns.

# Section 5: Development of a Single Model Construct

The ultimate goal of model development for the GRP is to have a single model construct that can be used to assess long-term flow and transport conditions consistently at both the site and basin scale. The GRP and SMC Basin Models will be developed separately to allow for efficient model testing and calibration without the additional computational burden of a single basin-scale model. The models will be merged into a single construct through the use of local grid refinement (LGR), which is supported within the MODFLOW-OWHM architecture. The MODFLOW LGR approach was developed to support the use of locally refined grids, allowing smaller parts of a larger model domain to be refined without refining the entire model grid (Mehl and Hill, 2005). This approach can improve simulation accuracy in local areas of interest while minimizing the computational burden that can arise from extending fine-scale grid spacing across an entire regional domain. In addition, modifications have been made to the MODFLOW-SFR package to allow for routing of surface flows through LGR grids (Mehl and Hill, 2010).

The LGR method links two (or more) finite-difference model grids: a coarse grid covering a large area which incorporates regional boundary conditions and a fine grid covering a smaller area of interest. The standard terminology within LGR for these grids is parent (coarse) and child (fine) grids. The parent and child grids are dynamically linked through iterative coupling, which allows for feedback (changes in water levels and fluxes) between the two grids. The role of the parent model is to provide boundary conditions to the child model that are consistent with the more regional flow system, while the function of the child model is to simulate flow at a finer scale than is reasonable for the parent model grid. Note that the parent and child grids do not need to share the same layer structure, simply the same top elevation of model layer 1 and the bottom elevation of the lowest layer in the domain.

LGR uses the iteratively coupled shared-node method. The child grid is nested within the parent grid, and the models join along interfaces. The parent and child models do not overlap model cell areas, but rather share "half cells", cells that represent only half the volume of a normal model grid cell. The iteratively coupled shared-node method balances heads and fluxes across the interfacing boundary of the two grids. The coupling procedure begins by simulating the parent model encompassing the entire domain. The simulated heads from this iteration are used to interpolate specified-heads at the interface for the child model. The child model is then simulated and fluxes through the interface are calculated. The parent model is then simulated again using these fluxes as part of an interior flux boundary. This process is repeated in the solution scheme until both the head and flux changes are smaller than user-defined criteria (i.e. solution convergence).

Using this method, the SMC Basin Model will form the parent model and the GRP Model will form the child model. LGR model development will proceed as follows:

- LGR interface information will be developed from the two models based on the model domain areas and layer structures.
- A simulation timeframe will be developed for testing the LGR model. This will likely be a shorter timeframe than either model calibration period to test LGR assumptions and development
- Model time-stepping and solution parameters will be tested and optimized for the short-period simulation.
- Model calibration for the HMC Mill site will be compared between the GRP Model and the LGR model to ensure the merged model simulates roughly the same flow conditions for the site.
- Longer-term simulations of past and potential future conditions will be developed consistent with simulations from the GRP and SMC Basin Models.

The single LGR model will be used as a tool to assess both site-scale and regional changes in response to ongoing remedial activities at the HMC Mill site and throughout the SMC Basin. The model will also be used to support constituent transport simulations at the site and regional scales.

# Section 6: Groundwater Model Report

Development and application of the GRP, SMC Basin, and LGR Models will be thoroughly documented in a project report. The report will be developed following ASTM guidelines for model documentation (ASTM D5718-13, Standard Guide for Documenting a Groundwater Flow Model Application, 2013), and will include both written and graphical presentations of model objectives, assumptions, code description, model set up, calibration, predictive simulations, and conclusions. The report will include appropriate figures, tables, and appendices to provide a complete understanding of model development, assumptions used, data sources, and how the model is applied to fulfill the stated objectives.

A general outline for the model report (based on ASTM guidance) is as follows:

- Introduction
- Modeling Objectives
- Regional and Site Hydrogeologic Setting
- Computer Code Description
- GRP Model Development
  - Domain and Layer Structure
  - Boundary Conditions
  - Physical Parameters
  - Sources and Sinks
  - Transport Parameters and Assumptions
  - Calibration Targets and Approach
  - Calibration Results
  - Predictive Simulations
  - Sensitivity Analysis
- SMC Basin Model Development
  - Domain and Layer Structure
  - Boundary Conditions
  - Physical Parameters
  - Sources and Sinks
  - Transport Parameters and Assumptions
  - Calibration Targets and Approach
  - Calibration Results
  - Predictive Simulations
  - Sensitivity Analysis
- LGR Model Development
  - Parent-Child Model Linkages
  - Boundary Heads/Fluxes

  - Time Period Selection
  - Transport Parameters and Assumptions
  - Historical Period Scenarios
  - Current and Future Scenarios
  - Sensitivity Assessments
- Summary and Conclusions

# Section 7: Summary

Groundwater flow and constituent transport models will be developed at the site (GRP) and regional (SMC Basin) scales based on the HSCMs described in BC, 2018. The ultimate goal of model development for the GRP is to have a single model construct that can be used to assess long-term flow and transport conditions consistently at both the site and basin scale. The GRP and SMC Basin Models will be developed separately to allow for efficient model testing and calibration without the additional computational burden of a single basin-scale model. The models will be merged into a single construct through the use of local grid refinement.

The GRP and SMC Basin Models will be developed using the USGS flow model MODFLOW-OWHM and the transport code MT3D-USGS, the USGS version of the popular MT3DMS code. The GRP Model will be an extension of a previously developed flow and transport model for the Site, while the SMC Basin Model will be new construct to simulate flow in regional aquifers. Three-dimensional geologic models using Leapfrog will be developed to provide stratigraphic information to the models, while physical parameters will be developed from site-specific data, previous studies, and regional geologic evaluations.

The merged LGR Model will be used as a tool to assess the following:

- Simulation of groundwater flow and hydraulic heads within the alluvial and bedrock (upper, middle and lower Chinle and San Andres) aquifers beneath the GRP.
- Simulation of fate and transport of site Constituents of Concern (COCs) for the GRP.
- Prediction of remediation time frame for GRP using current groundwater pump and treat methodology.
- If necessary, analysis of remedial alternatives associated with the GRP
- Simulation of groundwater flow and hydraulic heads for the regional-scale alluvial and bedrock aquifers within the San Mateo Watershed (SMC Basin).
- Simulation of fate and transport of COCs from the Ambrosia Lake area of the SMC Basin.
- Prediction of off-site San Mateo uranium-selenium plume movement towards the GRP.

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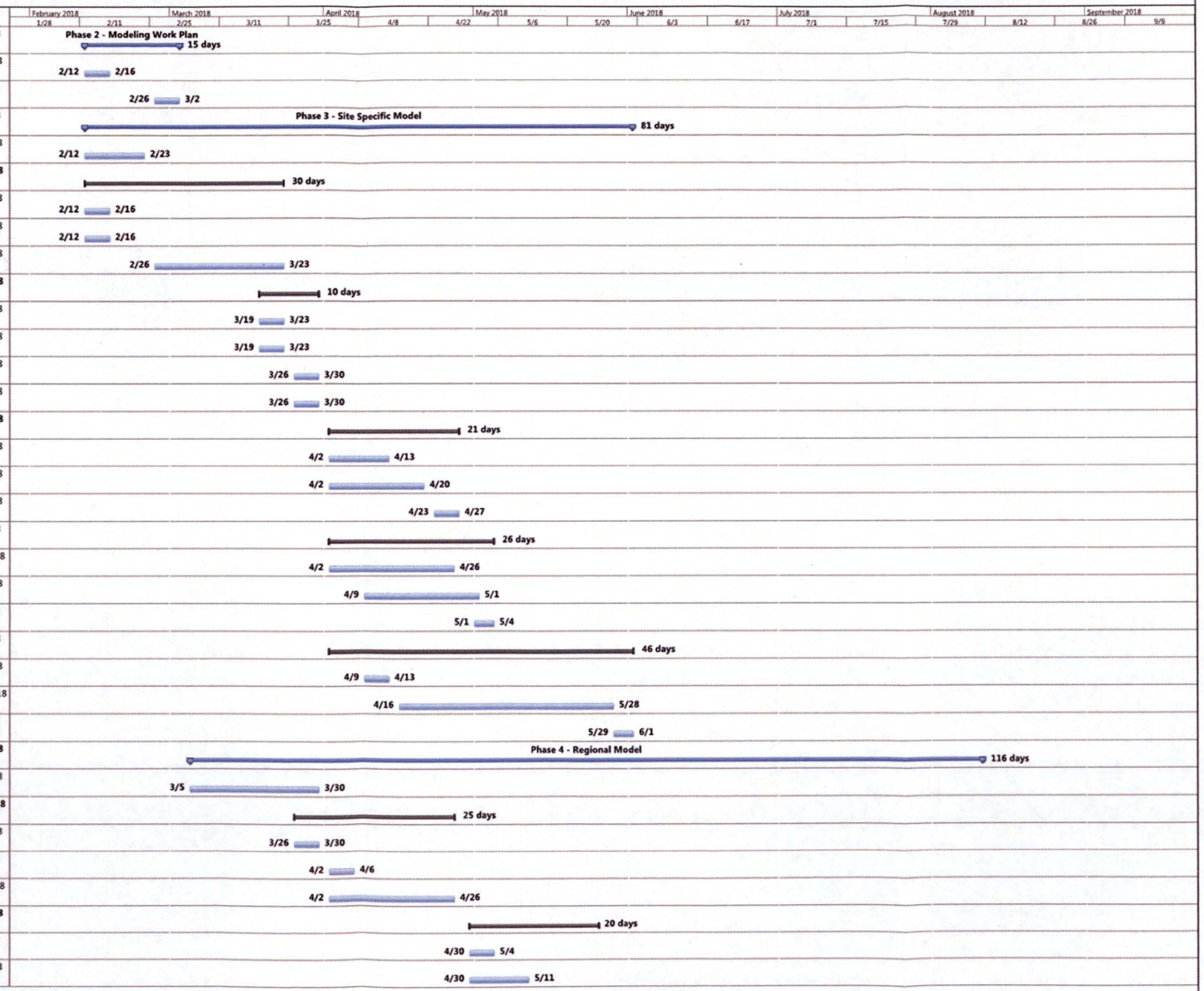
# Appendix A: Groundwater Modeling Schedule

HMC 2018 Groundwater Modeling Schedule

| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | **Phase 2 - Modeling Work Plan** | **15 days** | **Mon 2/12/18** | **Fri 3/2/18** |
| 2 | 2-1. Prepare Draft Work Plan | 5 days | Mon 2/12/18 | Fri 2/16/18 |
| 3 | 2-2. Finalize Work Plan | 5 days | Mon 2/26/18 | Fri 3/2/18 |
| 4 | **Phase 3 - Site Specific Model** | **81 days** | **Mon 2/12/18** | **Fri 6/1/18** |
| 5 | 3-1. Finalize HydroEngineering Model Review | 10 days | Mon 2/12/18 | Fri 2/23/18 |
| 6 | **3.2. Develop 3-D Geology Model in Leapfrog** | **30 days** | **Mon 2/12/18** | **Fri 3/23/18** |
| 7 | 3-2.1 Geologic Data Summary | 5 days | Mon 2/12/18 | Fri 2/16/18 |
| 8 | 3-2.2 Stratigraphic Interpretations | 5 days | Mon 2/12/18 | Fri 2/16/18 |
| 9 | 3-2.3 Prepare 3-D Model | 20 days | Mon 2/26/18 | Fri 3/23/18 |
| 10 | **3-3. Develop Groundwater Vistas Model Framework** | **10 days** | **Mon 3/19/18** | **Fri 3/30/18** |
| 11 | 3-3.1 Export Geologic Framework | 5 days | Mon 3/19/18 | Fri 3/23/18 |
| 12 | 3-3.2 Develop Groundwater Vistas File | 5 days | Mon 3/19/18 | Fri 3/23/18 |
| 13 | 3-3.3 Populate Vistas with Existing Parameters, Pumping, etc. | 5 days | Mon 3/26/18 | Fri 3/30/18 |
| 14 | 3-3.4 Create Test Files | 5 days | Mon 3/26/18 | Fri 3/30/18 |
| 15 | **3-4. Historic Flow Simulations and Calibration** | **21 days** | **Mon 4/2/18** | **Fri 4/27/18** |
| 16 | 3-4.1 Perform Historic Flow Simulations | 10 days | Mon 4/2/18 | Fri 4/13/18 |
| 17 | 3-4.2 Flow Model Calibration | 16 days | Mon 4/2/18 | Fri 4/20/18 |
| 18 | 3-4.3 Present Model Calibration to HMC | 5 days | Mon 4/23/18 | Fri 4/27/18 |
| 19 | **3-5. Contaminant Transport Modeling** | **26 days** | **Mon 4/2/18** | **Fri 5/4/18** |
| 20 | 3-5.1 Develop Transport Model (with input from Dave Levy) | 20 days | Mon 4/2/18 | Thu 4/26/18 |
| 21 | 3-5.2 Transport Calibration | 18 days | Mon 4/9/18 | Tue 5/1/18 |
| 22 | 3-5.3 Present Transport Calibration to HMC | 4 days | Tue 5/1/18 | Fri 5/4/18 |
| 23 | **3-6. Predictive Simulations** | **46 days** | **Mon 4/2/18** | **Fri 6/1/18** |
| 24 | 3-6.1 Develop Remedial Alternatives with HMC | 5 days | Mon 4/9/18 | Fri 4/13/18 |
| 25 | 3-6.2 Perform Remedial Simulations | 31 days | Mon 4/16/18 | Mon 5/28/18 |
| 26 | 3-6.3 Present Results to HMC | 4 days | Tue 5/29/18 | Fri 6/1/18 |
| 27 | **Phase 4 - Regional Model** | **116 days** | **Mon 3/5/18** | **Fri 8/10/18** |
| 28 | 4-1. Collect Additional Data | 20 days | Mon 3/5/18 | Fri 3/30/18 |
| 29 | **4-2. Develop 3-D Geology Model in Leapfrog** | **25 days** | **Mon 3/26/18** | **Thu 4/26/18** |
| 30 | 4-2.1 Data from Various Mill Sites | 5 days | Mon 3/26/18 | Fri 3/30/18 |
| 31 | 4-2.2 Regional Stratigraphic Assumptions | 5 days | Mon 4/2/18 | Fri 4/6/18 |
| 32 | 4-2.3 Prepare 3-D Model | 20 days | Mon 4/2/18 | Thu 4/26/18 |
| 33 | **4-3. Develop Groundwater Vistas Model Framework** | **20 days** | **Mon 4/30/18** | **Fri 5/25/18** |
| 34 | 4-3.1 Export Geologic Framework | 5 days | Mon 4/30/18 | Fri 5/4/18 |
| 35 | 4-3.2 Develop Groundwater Vistas File | 10 days | Mon 4/30/18 | Fri 5/11/18 |

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## HMC 2018 Groundwater Modeling Schedule

| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 36 | 4-3.3 Populate Vistas with Initial Parameters, Pumping, etc | 15 days | Mon 5/7/18 | Fri 5/25/18 |
| 37 | 4-3.4 Create test files | 10 days | Mon 5/14/18 | Fri 5/25/18 |
| 38 | **4-4. Groundwater Flow Model Development and Calibration** | **46 days** | **Fri 5/25/18** | **Fri 7/27/18** |
| 39 | **4-4.1 Develop Historic Simulations** | **21 days** | **Fri 5/25/18** | **Fri 6/22/18** |
| 40 | 4-4.2 Flow Model General Calibration | 18 days | Fri 5/25/18 | Tue 6/19/18 |
| 41 | 4-4.3 Model Sensitivity Analyses | 4 days | Tue 6/19/18 | Fri 6/22/18 |
| 42 | 4-4.4 Present Flow Model to HMC | 2 days | Thu 6/21/18 | Fri 6/22/18 |
| 43 | **4-5 Regional Transport Modeling** | **25 days** | **Mon 6/11/18** | **Fri 7/13/18** |
| 44 | 4-5.1 Develop Transport Model | 15 days | Mon 6/11/18 | Fri 6/29/18 |
| 45 | 4-5.2 General Model Testing/Limited Calibration | 13 days | Fri 6/22/18 | Tue 7/10/18 |
| 46 | 4-5.3 Present Transport Model to HMC | 4 days | Tue 7/10/18 | Fri 7/13/18 |
| 47 | **4-6 Regional Modeling Scenarios** | **15 days** | **Mon 7/2/18** | **Fri 7/20/18** |
| 48 | 4-6.1 Develop Regional Scenarios with HMC (past or future) | 5 days | Mon 7/2/18 | Fri 7/6/18 |
| 49 | 4-6.2 Perform Regional Scenario Simulations | 10 days | Mon 7/9/18 | Fri 7/20/18 |
| 50 | 4-6.3 Present Results to HMC | 5 days | Mon 7/16/18 | Fri 7/20/18 |
| 51 | **Phase 5 - Merge Models into Composite Model** | **20 days** | **Mon 7/23/18** | **Fri 8/17/18** |
| 52 | **5.1 Merge Models** | **15 days** | **Mon 7/23/18** | **Fri 8/10/18** |
| 53 | 5-1.1 Develop Boundary Condition Linkages | 5 days | Mon 7/23/18 | Fri 7/27/18 |
| 54 | 5-1.2 Composite Model Testing | 5 days | Mon 7/23/18 | Fri 7/27/18 |
| 55 | 5-1.3 Finalize Composite Model | 10 days | Mon 7/30/18 | Fri 8/10/18 |
| 56 | **5.2 Composite Model Simulations** | **20 days** | **Mon 7/23/18** | **Fri 8/17/18** |
| 57 | 5-2.1 Develop Composite Model Scenarios with HMC | 10 days | Mon 7/23/18 | Fri 8/3/18 |
| 58 | 5-2.2 Perform Scenario Modeling | 10 days | Mon 8/6/18 | Fri 8/17/18 |
| 59 | 5-2.3 Present Results to HMC | 5 days | Mon 8/13/18 | Fri 8/17/18 |
| 60 | **Phase 6 - Reporting** | **30 days** | **Mon 7/23/18** | **Fri 8/31/18** |
| 61 | 6-1 DRAFT Report | 25 days | Mon 7/23/18 | Fri 8/24/18 |
| 62 | 6-2 FINAL Report | 5 days | Mon 8/27/18 | Fri 8/31/18 |


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